An Innovation Approach for Sustainable Product and Product-Service System Development

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Abstract:
This thesis investigates the potential of User-Centered Design (UCD) and Agile to support Strategic Sustainable Development (SSD) practice in product and product-service system (PSS) design. UCD tools and concepts are used to support stakeholder and needs research. Agile provides process support for collaboration and resilience. SSD tools and concepts are used to define and work within the system boundaries for sustainability. All three practices are combined in an innovation approach that supports collaborative and cross-functional design teams as they develop products and PSS. Design teams using this approach will work to satisfy the needs of customers while considering the needs of all non-customer stakeholders and the ecosphere. The full-systems context emphasized in the approach will support innovation and encourage design teams to consider services as complements to, or substitutes for, physical products.

Keywords: Agile, User-Centered Design, Sustainable Product Development, Product-Service System Design, PSS, Strategic Sustainable Development, Innovation for Sustainability.

Statement of Collaboration

Acting on the firm conviction that design has the potential to lead society towards sustainability, we set out to research practical approaches to design innovation. In true Agile form, we worked collaboratively throughout the thesis period, checking in with each other daily, reflecting on our progress and process regularly, and continuously improving our cumbersome thesis title (every word of which is absolutely necessary). Writing was often done together. When deeper research was conducted on specific topics, the results were discussed with the group and then integrated into the collective document.

We all participated directly in interviews, workshop design and facilitation, and literature review. Qingqing and Pinar conducted several interviews in Chinese and Turkish respectively, and spent many hours translating notes to share with the others.

Kara has a background in user-centered web design, and shared agile concepts with us in a workshop at the beginning of the project. Because she is so hardworking and talented (and a native English speaker), she got the job of editor-in-chief, making sure that our writing was as clear and concise as possible. Her experience with and enthusiasm for UCD and Agile brought depth and richness to the content. She is a harmonious team partner and a good listener.

Pinar Öncel, a brilliant industrial designer and sustainability practitioner, contributed her deep understanding of product development to the research. She encouraged us to try new ways of brainstorming and harvesting results throughout the process. She conducted deep research on how design requirements related to human needs and satisfiers. Her close contact with designers brought significant feedback to our research. She brings her peaceful nature and strong sense of the "whole" to our work.

Qingqing Yang's background is in education rather than design, and so was responsible for ensuring that all design concepts were explained in plain language, contributing significantly to the clarity of this thesis. She also conducted in-depth research on the business case for sustainability. Qingqing made it possible to interview many Chinese companies and designers, rounding out our research. Her positive energy and joy constantly remind us to enjoy the fun things in life.

Acknowledgments

We would like to acknowledge the contributions of our thesis advisors, Tobias Larsson and Sophie Hallstedt. Tobias gave our class an inspiring lecture on PSS design at the beginning of the year, which sparked our enthusiasm for the topic. He has been no less inspiring throughout the course of our work and we would like to thank him for all of his time and advice as he helped our research along. Sophie was the original designer of the MSPD, and was very supportive of our efforts to find a new application for its components. She also provided invaluable feedback on our research structure and methods for which we are sincerely grateful.

We would also like to acknowledge the MSLS program staff for creating the environment of support that allows us to actively consider the sustainability challenge.

Our classmates have also contributed to this thesis, not only by providing regular Pilates, yoga, and belly dance breaks, but also by sharing their valuable time to bounce ideas around. Special thanks to our shadow group members (Anna Barkan, Daniel Gunnarsson, and Olaf Postel), to those who shared their relevant professional experience with us, and to those who participated in our experimental newspaper construction workshop.

Our thanks go out to interview participants and expert reviewers as well as other friends who showed any interest in our topic and were willing to have long conversations about the finer points of Agile, UCD, and Sustainable Product Development. We understood our topic so much more fully through their expertise, patience, and insight.

Finally, we would like to thank our loving families who have whole-heartedly supported all of our decisions in life, even the ones that mean we won't make an income for a while. Our enthusiasm for working towards a sustainable future is strongly rooted in our upbringing, and they have inspired and nurtured us in this respect.

Executive Summary

Background

Product design teams regularly run into barriers when they try to design for sustainability within the limits of their existing perceived product system. To do so effectively, they require a design approach that frees them from thinking strictly about specific materials and physical products and sets the stage for innovation.

Services can be used to dematerialize, customize, or replace product offerings. When products and services are used in combination to provide utility to a customer, they are called product-service systems (PSS), and offer great promise for the move towards sustainability.

Overarching sustainability principles can help design teams consider the full system as they design products. Mapping the life-cycle system of a product can reveal design decisions that may lead toward unsustainability, and identify opportunities for services and supplemental products to strengthen the entire system. Discovering the dynamics of user and business needs within the system can help distinguish true satisfiers from false satisfiers and dead ends. And an agile process approach can help design teams navigate risks and remain open to promising new opportunities.

This study seeks to answer the following questions:

1. How can design practices drawn from Agile and User-Centered Design (UCD) support innovation as design teams work strategically towards sustainability through product and PSS development?

    1.1. What are the key strategies for success in product and PSS development for sustainability?

    1.2. Which tools, concepts, and practices from UCD, Agile, and Strategic Sustainable Development (SSD) can contribute to that success, and how?

Research Approach

To understand the current reality and develop a practical innovation approach for design teams, the authors conducted as many interviews as possible with practitioners in the field. Because many practitioners are more likely to have contributed to the body of knowledge surrounding UCD and Agile through blog posts and online articles, rather than through academic papers, it was necessary to include online content in our literature review. To be sure that the recommendations were practical, it was necessary to conduct some testing, however, due to time constraints, they could not be tested through a full product development cycle. For this reason, the authors designed a short workshop to test certain process ideas, and then sent out the recommended approach for expert review from practitioners in the field.

Results

Maintaining or increasing revenue is the overarching single driver behind new product development. Companies primarily view sustainability as a trend, an opportunity to reduce expenses in specific areas, a niche market, or a necessary measure to comply with new legislation. However, companies that have chosen to work towards full sustainability have realized significant business profits.

Backcasting can be applied as an overarching strategy to help design teams understand the gap between their current reality and their project vision. They can then use the resulting creative tension to brainstorm a wide array of actions that might draw them towards that vision.

Three additional strategies guide product and PSS development towards sustainability and help design teams prioritize actions and manage trade-offs in design decisions.

Strategy 1 – Move in the right direction

Design teams must be able to easily assess whether or not certain design choices will lead towards sustainability and success according to their product vision. The authors found two related barriers and weaknesses in current practices with respect to innovation towards sustainability.

- Existing technology and materials are limiting.
- Market research discovers customer preferences, not user needs.

There are several practices in SSD, and UCD that may help design teams to overcome these barriers.

- Tools such as the MSPD, TSPDs, and SLCA can be used along with the four sustainability principles to guide sustainable product development.
- Life-cycle mapping helps identify stakeholders and system components. User research/Needfinding methods can then help discover the latent needs of all stakeholders. Manfred Max-Neef provides a definition of nine human needs that may serve as additional context for needfinding research.

Strategy 2 – Build resilience

Design teams must be able to able to manage risk, quickly recover from change and remain open to new opportunity. The authors found three related barriers and weaknesses in current practices with respect to innovation towards sustainability.

- Limited systems view hides rebound effects and sustainability risks.
- Design teams tend to define solutions before context is understood.
- The design dilemma inhibits innovation.

The following practices in SSD, UCD, and Agile may help design teams to overcome these barriers.

- System mapping and causal loop diagrams can help identify sustainability risks.
- The concept of "Iteration 0" may serve as a discovery phase to establish context for a design project. During this phase, artifacts such as experience maps can trigger ideas for new solutions. A process facilitator can help to ensure that detailed solutions aren't designed before context is fully understood.
- Backcasting from principles, lean requirements, continuous improvement, iterative work cycles and rapid prototyping are all tools or concepts that can be used to reduce risk and facilitate quick response to changing circumstances.

Strategy 3 – Provide business value

The primary driver of new product development is to gain market share and increase revenue. The authors found three related barriers and weaknesses in current practices with respect to innovation towards sustainability.

- Mass production models inhibit dematerialization
- Strong focus on physical products limits opportunities for PSS development
- Organizational structures inhibit collaboration

The following practices and concepts within SSD, UCD, and Agile may help design teams to overcome these barriers.

- Risk management and cost savings are being realized through eco-efficiencies. Lean practices help with dematerialization, reduced cost of production, and reduced cost of change. Removing barriers to user modification can also eliminate the need for multiple customized models of a particular product.
- System mapping and causal loop diagrams help identify innovation opportunities or leverage points. Experience mapping can trigger ideas for new solutions, and iterative cycles can invite innovation into a process.
- Agile methods support collaboration, facilitating innovation and reducing communication overhead.

Discussion

UCD practices bring value to product and PSS development by shifting the focus of design from market preferences to user needs. They can also supplement existing SSD practices by strengthening the application of the fourth sustainability principle within product and PSS design. The authors recommend researching and documenting needs and barriers for all users on three levels - preferences, functional requirements, and human needs.

Through lean design, short iterative cycles and regular reflection and adaptation, agile methods increase the likelihood that nearly any measure can serve as a flexible platform.

In sustainable product development, collaborative partnerships must be managed across supply chains and through the end of a product's life. Agile methods place emphasis on collaboration over documentation, and explicitly support teamwork and partnership management, placing high value on building and harnessing the expertise of individual team members to support innovation and efficiency.

For optimum success, UCD, Agile, and SSD tools and concepts may be used together in a way that strengthens potential for innovation toward sustainability in product and PSS design. This thesis proposes an innovation approach that combines "Iteration 0," a discovery phase, with iterative work cycles and suggestions for product launch and maintenance.

Key findings

- UCD processes can contribute to innovation for sustainability when human needs and non-customer stakeholders are considered during the design process.
- UCD can strengthen the application of the fourth sustainability principle within product and PSS design.
- Agile methods can support a backcasting approach to design flexible platforms.
- A time-limited discovery phase (Iteration 0) supports consideration of a complex system.
- Agile can support innovation for sustainability by reinforcing reflection and consideration of the system.
- Switching to Agile methods involves an initial learning curve.
- Cross-functional teams that transparently include project stake-holders contribute to innovation for sustainability.

UCD practices may help design teams understand the context of the full system when applied to all stakeholders along the life-cycle of a product. The traditional understanding of user needs in UCD practice must be supplemented with a clear definition of human needs to lead a design process towards sustainability. The authors also recommend using an iterative agile approach with a brief discovery phase to manage the design process.

As solving the sustainability challenge requires teams to innovate and find new ways of doing things, methods that support collaborative work, pulling expertise from many areas and reinforcing a shared vision of the system, are important to design for sustainability.

Glossary and Acronyms

Glossary

Agile: A term used to describe a set of values in product development. There are several methods and tools that can also be considered “agile,” and are used in support of these values. Agile originated in the manufacturing industry as a way to increase productivity, promote innovation, and reduce risks associated with rapidly changing market demands. (Patton 2009; Braaten 2010; Kettunen 2009)

Backcasting: A technique used to envision a desirable future in which success has been met so that a plan can be generated describing what must now be done to move towards that point (Holmberg and Robèrt 2000).

Products: Artifacts that can be touched, stored and owned by specific individuals or groups (Roy 2000)

Product-Service System (PSS): Products and services used in combination to provide utility to a customer (UNEP 2001, 3).

Service: Any act or performance that one party can offer to another that is essentially intangible and does not result in the ownership of anything. Its production may or may not be tied to a physical product (Kotler 1988).

User-Centered Design (UCD): An approach to design that grounds the process in information about the people who will use the product. UCD processes focus on users through the planning, design and development of a product (UPA 2010).

Acronyms

CLD	Causal Loop Diagram
DFE	Design for Environment
D4S	Design for Sustainability
FSC	Forest Stewardship Council

FSSD	Framework for Strategic Sustainable Development
IUCN	International Union for Conservation of Nature and Natural Resources
LCA	Life Cycle Analysis
MSPD	Method for Sustainable Product Development
PSS	Product Service System
SLCA	Sustainable Life Cycle Analysis
SP	Sustainability Principle
SPD	Sustainable Product Development
SSD	Strategic Sustainable Development
TNS	The Natural Step
TSPD	Templates for Sustainable Product Development
UCD	User-centered Design
UNEP	United Nations Environment Programme
WWF	World Wide Fund For Nature
YTB	Yesterday Today Blockers

Table of Contents

List of Figures and Tables

1. Introduction

1.1. Designing an innovation approach for a sustainable future

As one industrial designer laments, “In the world of plastics and injection molding, all we have are less bad materials. Plastics are theoretically recyclable, but few industries do it, and nobody wants to use recycled plastic because of purity concerns” (McGuire 2010). Eco-design practices provide guidelines to help minimize the effects of those “less bad” materials. But, design teams regularly run into barriers when they try to improve products within the limits of an existing system.

There is great business value in designing for sustainability, outside of manufacturing processes as well as within (Willard 2005). To do that, design teams require more than a database of safe materials, since it is often not the materials themselves that are unsustainable. Rather, the relative sustainability of materials is determined by the way that they are managed and whether or not they can be reclaimed into natural or manufacturing cycles at the end of a product’s life. Design teams require a design approach that frees them from thinking strictly about specific materials and physical products and sets the stage for innovation. An overarching approach such as strategic sustainable development (SSD), that considers sustainability at a principle level, can help to make sense of disconnected tools and practices.

Physical products are part of a larger system that can be mapped and considered during a product development process. System mapping can make clear those decisions that may lead toward unsustainability, and identify opportunities for services and supplemental products to strengthen the entire system.

Discovering the dynamics of user and business needs within the system can help distinguish true satisfiers from false satisfiers and dead ends. And an agile process approach can help design teams navigate risks and remain open to promising new opportunities.

In this thesis, the authors outline an innovation approach to support design teams working with organizations on sustainable product and product-service system (PSS) development. To effectively design products and PSS that work in balance with the natural system, and to apply solutions to the problems we currently face, design teams need to begin with a clear understanding of the system and what keeps it running smoothly.

1.2. Products within systems

"If you see a whole thing - it seems that it's always beautiful. Planets, lives ... But close up a world's all dirt and rocks. And day to day, life's a hard job, you get tired, you lose the pattern."

Ursula K. Le Guin (Le Guin 1974)

Our world is a complex, non-linear system with vast networks of subsystems. This larger system cannot be understood simply as a sum of its parts; the practice of systems thinking shows us that the relationships between those parts define the properties of the whole (Capra 1985). Each of us has relationships with people, nature, and our built environment. Each of them, in turn, has relationships with the others. There are also broad dependencies in the system; individual wellbeing relies heavily on the wellbeing of society, which is deeply interconnected with the state of the ecosphere (Lucas 2007; Carlisle 2008).

Products within the system can impact relationships between other parts of the system. Services related to those products can do the same. For example, cell phones and services offered by phone companies facilitate relationships between people, while scuba gear helps people interact with nature, and sea walls prevent the sea from eroding the beach. However, due to the complexity and interdependency of the system, a product that helps one relationship may, inadvertently, harm another. This harm may manifest as climate change, resource depletion, pollution, biodiversity loss, poverty, or countless other symptoms that indicate an imbalance in the system (International Futures Forum 2010). Because people create products and services, people can change them to correct the imbalances that they have caused.

Attempts to remedy harm caused by the manufacture, use, or disposal of physical products have often focused on end-of-pipe solutions like pollution control, treating symptoms rather than eliminating the source of the problem (Hallstedt 2008). In recent years, cleaner production approaches have taken aim at products and industrial processes as the source of the problem (UNEP 2001). One solution to crowded landfills is to reduce packaging. Appliance designers can reduce carbon emissions by making products more energy efficient. These solutions may represent positive steps, but are still inadequate to bring us toward a sustainable society. A report published by UNEP holds that, “we need to move towards a point where we are reliant on 10% of the resources that are consumed by industrialized countries today (per capita)” (UNEP 2001). To bring product manufacture and use to a point where it doesn't harm the system, we need to revise our understanding of physical products as independent objects and begin designing for products and related services within systems.

1.3. Products and PSS in a sustainable society

1.3.1. Defining Sustainability

The Brundtland Commission Report defines sustainable development as “meeting the needs of the present without undermining the ability of future generations to meet their needs” (Brundtland 1987, 43). IUCN, UNEP, and WWF define it as “improving the quality of human life while living within the carrying capacity of supporting ecosystems” (IUCN et al. 1991).

To bring these broad definitions into a form that we can use as a design constraint, we need to understand what might undermine the ability of future generations to meet their needs. In other words, we need to know what causes *unsustainability* (The Natural Step 2010). The Natural Step, an international NGO, uses four principles as guidelines for what we must do to become a sustainable society. These four principles are based on an understanding of the conditions that cause unsustainability.

“To become a sustainable society, we must:

1. Eliminate our contribution to the progressive buildup of substances extracted from the Earth's crust (for example, heavy metals and fossil fuels)

2. Eliminate our contribution to the progressive buildup of chemicals and compounds produced by society (for example, dioxins, PCBs, and DDT)

3. Eliminate our contribution to the progressive physical degradation and destruction of nature and natural processes (for example, over-harvesting forests and paving over critical

wildlife habitat); and

4. Eliminate our contribution to conditions that undermine people's capacity to meet their basic human needs (for example, unsafe working conditions and not enough pay to live on)."

(The Natural Step 2010)

There are other methods and frameworks that provide guidelines for sustainable product development, such as Design for Sustainability (D4S) (Design for Sustainability 2010) and Design for Environment (DFE) (Fiksel 2009). However, for the purposes of this study, we will focus specifically on how the four sustainability principles listed above may guide product development towards sustainability. These principles were the result of a process of consensus building in the scientific community. This process was initiated by Karl-Henrik Robèrt, cofounder of The Natural Step, an international NGO, and began by identifying ways in which human society could upset the natural balance of the system. The four sustainability principles are grounded in science and provide a high-level, non-overlapping, "just-enough," set of design requirements for sustainability (Holmberg et al. 1996).

1.3.2. Considering sustainability in product design

A basic investigation of physics can help explain this definition of sustainability and how it relates to physical products. The conservation laws state that matter and energy are neither created or destroyed, but only change form. While the earth is an open system to energy, it is, for all practical purposes, a closed system for matter. That is to say that only meteorites and rockets really ever enter or leave the system. This means that we have finite resources on our planet. Energy is required to mold those resources into structured products and energy is released as they break down again, but everything runs through these cycles of structuring, degradation, and restructuring. There are natural flows of elements between the ecosphere (where life exists) and the lithosphere (the earth's crust) (see Figure 1.1 below). If we increase those flows through human activity such as extraction, we risk increasing concentrations of elements from the lithosphere in the ecosphere to the point where they can become toxic to life. (Broman, Holmberg, and Robèrt 2000)

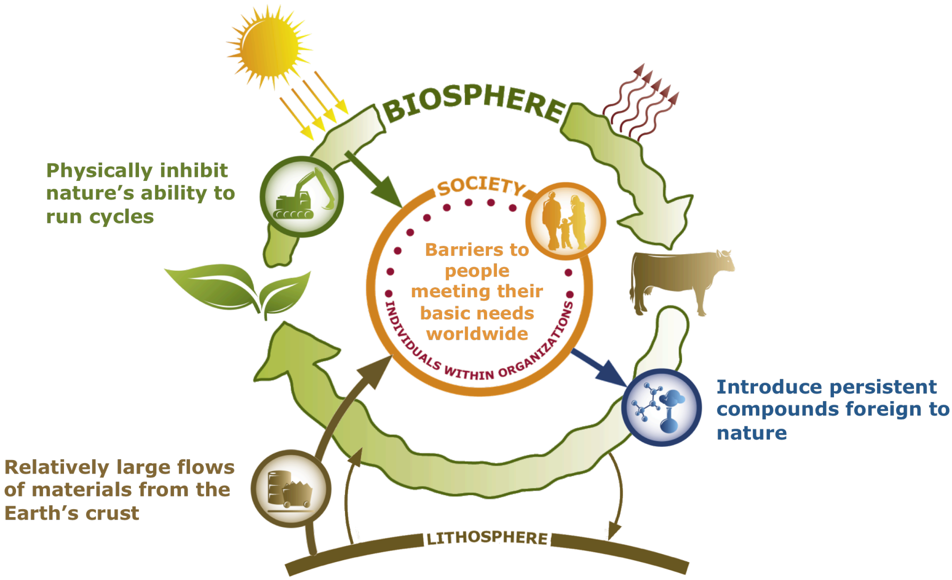

Figure 1.1. Society within the ecosphere and the conditions that cause unsustainability. (The Natural Step Canada 2009)

The four sustainability principles can help design teams consider this full system as they design products. Understanding what keeps the natural system in balance is critical if we are to avoid throwing it out of balance through our actions.

- *Products and Sustainability Principle 1* - Fossil energy was formed inefficiently over time. In "Burning Buried Sunshine," Jeffrey Dukes calculates that approximately "89 metric tons of ancient plant matter were required to create 1 U.S. Gallon [3.8 L] of gasoline" (Dukes 2003). When we rely on fossil fuels in the manufacture or use of our products, we bind ourselves to a limited resource and increase flows of carbon from the lithosphere to the ecosphere.

  If we design products using rare elements mined from the earth's crust, and we extract it faster than it can return to the earth's crust, concentrations in the ecosphere will eventually reach a point where they are toxic to life. (Broman, Holmberg, and Robèrt 2000)

- *Products and Sustainability Principle 2* - If we design products using man-made materials or chemicals that will not break down and return to nature efficiently, we will either use more energy to speed up that process or we will pollute our air, land, and water with those persistent substances. (Holmberg et al. 2000)

- *Products and Sustainability Principle 3* - If we design products that use resources and destroy habitat faster than they can be restored, we systematically rob ourselves of future use of the same resources. (Holmberg et al. 2000)

- *Products and Sustainability Principle 4* - In addition, humans are affected by a deteriorated or polluted ecosystem, impacting their ability to meet their basic human needs. Labels such as "Fair Trade" and "FSC Certified" indicate that human and natural resources are valued more realistically, reducing the human impacts of resource depletion and exploitation of labor (Robèrt et al. 2000).

1.3.3. PSS and sustainability

Services can be used to dematerialize, customize, or replace product offerings. Many product offerings are a combination of physical products and services rather than a pure form of either (see Figure 1.2). When products and services are used in combination to provide utility to a customer, they are called product-service systems (PSS). (UNEP 2001, 3)

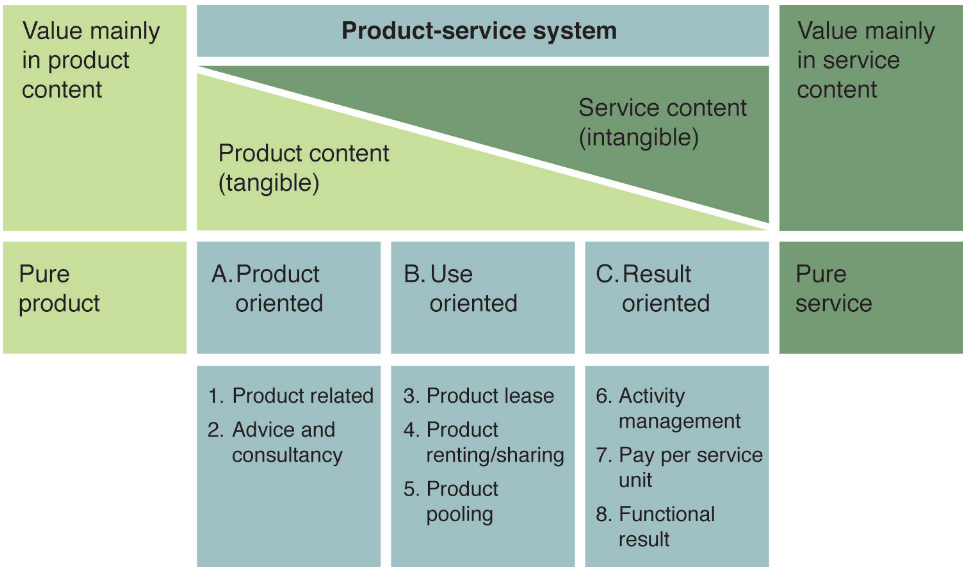

Figure 1.2. Product-service systems. (Tukker and Tischner 2004)

According to a UNEP report on PSS and sustainability, "the PSS concept is a possible and promising business strategy potentially capable of helping achieve the leap which is needed to move to a more sustainable society" (UNEP 2001, 3). PSS do not necessarily lead to more sustainable solutions. However, they can be designed with sustainability as a goal by including the four sustainability principles as design parameters.

For an example of how this might work, the four sustainability principles can be applied in a brief analysis of Zipcar (Zipcar 2010), a company operating in the US, UK, and Canada. Zipcar maintains fleets of cars, but is essentially a service company that offers convenient personal transportation. By making it easy to share vehicles and decoupling their revenue model from the manufacture of physical products, they have reduced the need for and impact of independently owned personal vehicles (DC Department of the Environment 2009). This brings society closer to compliance with all four sustainability principles.

- *Zipcar and Sustainability Principle 1* - Vehicle sharing reduces the number of vehicles needed in society, which translates to conservation of fossil fuels used in manufacturing and any rare elements used in electrical components. As of April 2009, Zipcar estimates that it has taken 100,000 vehicles off the road (DC Department of the Environment 2009).

- *Zipcar and Sustainability Principle 2* - Beyond the elimination of emissions resulting from vehicle manufacture, rental models discourage everyday use of personal vehicles, and Zipcar customers report increased use of public transportation (DC Department of the Environment 2009).

- *Zipcar and Sustainability Principle 3* - Reducing the number of vehicles on the road can reduce traffic congestion. Lighter traffic can reduce demand on transportation infrastructure such as roads, which cause environmental degradation.

- *Zipcar and Sustainability Principle 4* – Zipcar's technical services, dedicated parking locations, and rental model that includes fuel and auto insurance coverage enable urban dwellers to transport themselves freely with a lower investment than personal vehicle ownership would require. Zipcar claims that their members report an average monthly savings of $500 when compared to personal vehicle ownership (Zipcar 2010).

1.4. Moving product and PSS design towards sustainability

The four sustainability principles and an understanding of the system provide clear parameters to begin a design process. However, further guidance is necessary throughout the process to achieve a desirable result. The Framework for Strategic Sustainable Development (FSSD) used in this study is also widely known as The Natural Step (TNS) framework. This framework moves practitioners strategically towards sustainability by managing complexity and supporting a full-systems understanding of both problems and solutions. In this five-level framework, level one defines the system, level two defines success, level three sets strategic guidelines, level four outlines actions, and level five brings in tools that are relevant to the problem at hand (Robèrt et al. 2002; Robèrt 2000). The FSSD and related tools comprise Strategic Sustainable Development (SSD), a "strategic planning approach based on scientific principles and a holistic understanding of sustainability, designed to support decision making towards a sustainable society" (Balaskas, Lima, and Seed 2009).

Additional tools and concepts drawn from fields of practice such as User-Centered Design (UCD) and Agile can support design teams in their process as they work towards sustainability in product and PSS development. The authors believe that these tools and methods can facilitate innovative leaps that move society towards sustainability.

1.4.1. Innovative leaps towards sustainability

When applying the FSSD to the product development process, the "system" level would describe the relationship between the product and other parts of the system. At a basic, high level, this would mean that design teams must consider their product or service as it relates to their organization within society within the ecosphere, recognizing the implicit dependencies in that system. "Success" would be framed as a solution that serves the interests of the organization by satisfying customer needs within the constraints of the system. The four sustainability principles can serve as design constraints on this level.

From there, a planning methodology called "backcasting" is used as an overarching strategy to determine actions that might lead to success (Robèrt 2000; Robèrt et al. 2002). Backcasting uses the vision of future success to provide creative tension, allowing teams to brainstorm a wide array of actions that might draw them towards that vision. Possible paths can then be plotted by using strategic guidelines prioritize actions that can serve as stepping stones to support future improvements. Because the vision of success is set at a principle level and supported with a full systems understanding, the limitations of current technology or circumstances are less likely to inhibit innovation. By contrast, forecasting, the dominant planning methodology in large organizations, determines actions based upon previous and current trends. The results are incremental and focused on fixing current problems (Robèrt 2000).

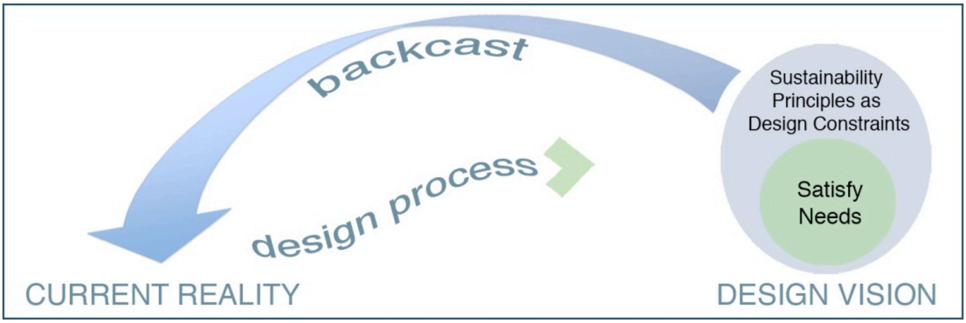

Figure 1.3. Backcasting from a design vision of satisfying needs within sustainability constraints

Case Study: Backcasting from the four sustainability principles as a catalyst for innovative leaps

In 1994, a client asked Ray Anderson, the CEO of Interface Carpets, what his company was doing for the environment. They were a carpet company, and at the time, they were not doing anything. Anderson enlisted the help of The Natural Step to help put his company on a track to full sustainability. They incorporated sustainability into their vision, hired a new President of Research and Development, Mike Bertolucci, and started to map out the high risk areas of their process along with opportunities for improvement.

When they looked at the second and third sustainability principles, they realized that their pattern dying process used about 90% of the water consumed in their entire operation. The fact that the water was used for dye meant that it also needed to be cleaned before it was released back into nature.

Instead of making the dying process more efficient, or implementing tighter controls on effluent waste, Bertolucci and his team discovered a way to eliminate water from the process altogether by using pre-dyed fibers in the carpet. This did not mean that the fibers were just being dyed somewhere else. Because the fiber was plastic, it meant that the colorant was baked into the plastic fibers before they were woven into carpet.

By releasing the design team from the constraints of existing operations, and adding the constraints of sustainability to the design requirements, this design team was able to make an innovative leap that significantly improved their product, reduced their resource use, and brought them closer to sustainability. (Bertolucci 2010)

SSD offers many other tools and methods that contribute specifically to the field of sustainable product development, such as the Method for Sustainable Product Development (MSPD) (Hallstedt et al. 2007a), the Templates for Sustainable Product Development (TSPDs) (Ny et al. 2008), and the Sustainable Life Cycle Assessment (SLCA) (The Natural Step 2010a). The MSPD offers a phased approach based on concurrent engineering that combines relevant product development questions with sustainability questions and uses a prioritization matrix intended to guide decisions. The TSPDs are presented as a supplement to the MSPD, and offer brief, scripted questions intended to aid product developers as they consider human and market needs, lifecycle impacts (using the SLCA), and potential for extended enterprise, including services that can be offered around the products. System dynamics and the use of causal loop diagrams can also contribute to sustainable PSS innovation (Byggeth et al. 2007b).

1.4.2. User-centered design as a catalyst for innovation

Products and services are typically designed either for consumers, the "users" of these products and services, or for other business clients. UCD provides value by discovering and then answering end-user needs, even when the products are being designed for other businesses, rather than designing products based on business needs and then using knowledge about potential audiences to manipulate demand. UCD argues that understanding what is good for a user is good for a business (Patnaik and Becker 1999).

Life-cycle system maps may be used to identify all affected product stakeholders, whether or not they are not direct customers of a product. When using UCD practices with sustainability as a goal, the definition of users can be extended to include all stakeholders. UCD practices such as needfinding (Patnaik and Becker 1999), experience mapping (nForm 2010), and persona development (Madsen and Nielson 2010) can help design teams better understand all users.

The authors will examine user needs in the context of the nine distinct human needs categorized by Manfred Max-Neef. The concepts of "needs" and "satisfiers" in Max-Neef's approach provide a clear understanding of how products and services relate as "satisfiers" of basic human needs (Max-Neef 1991).

Mapping the system and understanding user needs and potential satisfiers may reveal leverage points, where small changes to products or services could have the greatest beneficial impact (Meadows 1999).

1.4.3. Agile as a catalyst for innovation

"Agile" is not one specific method or tool; rather, it is a term used to describe a set of values in manufacturing and software product development (Patton 2009, Braaten 2010). There are several methods and tools that can be considered "agile," as they are used in support of these values. Agile originated in the manufacturing industry as a way to increase productivity, promote innovation, and reduce risks associated with rapidly changing market demands (Kettunen 2009). It was widely adopted in the software industry in time, and its values were summarized neatly in 2001 in the form of "The Agile Manifesto" (Agile Manifesto, 2001). This manifesto was accompanied by a set of 12 project management principles, and currently forms the backbone of most agile practices in the software and web development world. Through the manifesto and these principles, the software industry's adaptation of Agile redirected the focus from risk management and productivity to team support, iterative development, and customer collaboration. Recent developments in the web and software industry have integrated user-centered design more fully and proposed processes that build user experience design into iterative development cycles (Smith and Salvendy 2009).

There is currently no universally accepted set of agile principles that includes manufacturing, and varying practices and methods can be found across industries, but most share the basic characteristics listed under each point below. The authors believe that this list represents key values that have potential to support innovation as design teams work towards sustainable product and PSS development.

1. *Collaboration* – Cross-functional teams include key stakeholders and users as directly as possible. Face-to-face collaboration or side-by-side work is highly valued for efficient problem-solving and idea generation.

2. *Trust in individual team members* – Team members are seen as skilled and valued assets. They are given the freedom to organize their own time and solve problems as they see fit, rather than following strict specifications that have been passed along.

3. *Flexibility and openness to change* – Requirements are defined only as necessary along the way, and always with the idea that they may change again. Lean teams, requirements definitions, and processes contribute to flexibility.

4. *Freedom to innovate* – New ideas are perceived as opportunities, responsibility for decision-making is shared, and failures are not viewed as individual "mistakes," but as learning experiences. Because work is performed in rapid, iterative cycles, pursuit of new opportunities is less expensive and failures are identified and corrected quickly.

5. *Continuous improvement* – Reflection and adaptation are explicitly encouraged in both processes and products.

(Kettunen 2009; Agile Manifesto 2001; Fowler, 2005)

While agile approaches can promote flexibility in design and in process, they do not lack structure. As Martin Fowler states, agile methods "attempt a useful compromise between no process and too much process, providing enough process to gain a reasonable payoff" (Fowler 2005). Changes are often made within an agile process, and are even encouraged as improvements, but those changes should be made in a considered way and accepted by all members of a design team.

1.5. Purpose of the study and research questions

The purpose of this study is to help design teams innovate towards a sustainable society by designing for full systems rather than individual components, and by using processes that encourage collaboration and embrace change. The vision of a sustainable society is guided by the four sustainability principles, and considers user needs and business needs, along with the needs of non-customer stakeholders, society, and nature as a whole. The authors of this thesis investigate the potential of tools and concepts used in User-Centered Design (UCD) and Agile to cultivate innovation as design teams work towards sustainability through product and PSS development.

The authors aim to answer the following questions:

1. How can design practices drawn from Agile and User-Centered Design (UCD) support innovation as design teams work strategically towards sustainability through product and PSS development?

    1.1. What are the key strategies for success in product and PSS development for sustainability?

    1.2. Which tools, concepts, and practices from UCD, Agile, and Strategic Sustainable Development (SSD) can contribute to that success, and how?

2. Research Approach

2.1. Scope and limitations of the study

This study recommends a generic approach to the design process for products and PSS within organizations towards a sustainable society. The authors conducted interviews and tested their results with a limited number of experts across a broad spectrum of product sectors. While general conclusions about product development can be drawn from these interviews, further research could be done within specific sectors.

Due to time constraints, the goal of this study was to make recommendations for an innovation approach for product and PSS design. The authors were able to collect feedback on these recommendations from expert reviewers, but there was no opportunity for a product development team to apply these recommendations and provide feedback on the process. Action research should be performed in the future to more thoroughly test the recommended approach.

2.2. Research design

The authors considered this thesis itself a "product" and borrowed inspiration from agile methods during their "product development" process. This was partly to gain familiarity with the idea of structured flexibility and regular reflection, and partly because daily check-ins and regular reflections support collaborative work. A bi-weekly iterative cycle of plan, work, reflect and adapt was employed, while other practices were embedded in the process as necessary to answer the research questions (see Figure 2.1).

The *Plan* stage included short daily meetings with a YTB exercise (yesterday, today, and blockers), and planning for each iterative cycle, or "iteration."

The *Work* stage involved literature review, interviews with industrial designers, engineers, product developers, marketing managers, sustainability officers and top management, workshops, persona development, conversations with experts, and integration of all UCD, Agile, and SSD methods.

The *Reflect* stage involved testing ideas through case studies and expert review, checking in with advisors and shadow groups, conducting an experimental workshop, and bi-weekly retrospective meetings where the thesis authors discussed their own reflections on the process.

Finally, areas for further research, ideas that need further clarity, and recommended process changes were identified and handled in the *Adapt* stage.

Figure 2.1. Thesis development process.

2.3. Methods

To understand the current reality and develop a practical innovation approach for design teams, it was important to conduct as many interviews as possible with practitioners in the field. In addition, many practitioners have contributed to the body of knowledge surrounding UCD and Agile through blog posts and online articles, rather than through academic papers, so it was necessary to include online content in our literature review. To be sure that the recommendations were practical, it was necessary to conduct some testing. However, due to time constraints, recommendations could not be tested through a full product development cycle. For this reason, the authors designed a short workshop to test certain process ideas, and then sent out the recommended approach for expert review from practitioners in the field.

2.3.1. Literature, web content review

To research the relevant fields of study, the authors conducted searches in several academic databases to find peer reviewed articles on Agile, product development, product service systems and sustainable product development. Past theses and doctoral dissertations were included in this review, along with several books on product development and innovation.

By the nature of the topic, there is a wealth of well-regarded content available online. The authors have included information found online from reliable sources.

2.3.2. Interviews

To assess current best practices in product development and discover drivers for new product development, interviews were conducted with people involved at every stage of a product design process. The authors interviewed 22 professionals from different sectors and stages of product development: three marketing managers, eight industrial designers, five strategic managers, three project managers, two engineers, and two sustainability managers. Interview subjects were from different countries, including Canada, China, Germany, Israel, Sweden, Turkey, and the USA. They were also from many sectors within product development, including cosmetics, adhesives, glassware, consumer electronics, autos/auto parts, business electronics, retail/office space, tablecloths, small toys and furniture, detergent containers, packaging, brand collateral, ships, furniture parts and carpet tile. (See Appendix A)

Interviews were informal and semi-structured, following a basic script. After interviews were conducted, notes were reviewed and validated by interview subjects.

The interview questions consist of four basic topics:

1. *Product Initiation:* How and why do you start on new products/ projects?
   In this section of the interview, the aim was to understand the driving forces behind new product initiation.

2. *Project Process:* How does your typical product development process work?
   The aim of this section was to understand the dynamics of team structure and the project process.

3. *Partnerships:* How are partnerships made or managed to successfully create a whole product?
   These questions focused on collaboration and communication among internal and external stakeholders.

4. *Sustainability:* How are you incorporating sustainability into your product design process?
   The aim of this topic was to understand how sustainability is currently considered in product development, what challenges exist in that respect, and which tools are most helpful for that purpose.

Interview results were collected and harvested using a matrix designed to assess the current state of product development with respect to both innovation and sustainability (see Appendix B).

2.3.3. Experimental workshop

To test process ideas, the authors designed and conducted an experimental workshop with local participants. The workshop was designed to investigate possible project process approaches with regard to expected results of the thesis questions, make observations, and get feedback from participants.

- Effects of varying levels of upfront planning on project vision and team comfort.
- Effects of iterative time-boxes on risk-taking behavior.
- Effects of enforced iterative reflection on comfort level and regular exploration of new ideas.

See Appendix C for a full description of the workshop.

2.3.4. Expert review

The authors kept a blog through the course of the discovery process to compile ideas and facilitate discussion with experts and advisors. To validate the final results of the study, the authors submitted the recommended product innovation approach to Agile experts and stakeholders involved in product development for formal review. See Appendix A for a list of collaborators and Appendix D for review questions and an evaluation matrix used to rate tools and concepts.

3. Results

The authors began their research by conducting a literature review and interviews with practitioners in the field to learn why new products are developed, or what would make a successful product or PSS. This also helped the authors understand what strategies could be used to guide teams towards success, what barriers and weaknesses in current practices hindered that success, and what strengths and opportunities exist in current practice that would aid sustainable product development.

Interviews with practitioners identified many common goals, barriers, opportunities, strengths, and weaknesses in current design practice across sectors. In many cases, these findings were supported by literature review. Barriers were then mapped to the strategic guidelines, and tools and concepts from UCD, Agile, and SSD were selected to overcome each barrier.

3.1. Defining success in product and PSS innovation towards sustainability

Identifying the drivers of new product development informs an understanding of what makes a successful product or PSS. With these success criteria in mind, strategic guidelines may then be defined to lead a design process towards that success. This is necessary to answer research question 1.1, "What are the key strategies for success in product and PSS development for sustainability?"

3.1.1. Drivers of new product development

- *Innovation to gain or retain market share.* Maintaining or increasing revenue is the overarching single driver behind new product development. Businesses, by nature, pursue monopolies or niche markets to increase market share and revenue. It is government regulation that enforces competition (Marquez 2010). Companies develop new products to avoid losing market share, to stay ahead of competitors, or to take advantage of strong brand value to increase market share (Guven 2010). Competition and changing market trends create continuous pressure for companies to develop new materials, technologies, and products. (Kettunen 2009; Akman 2010; Guven 2010; McGuire 2010; Anon.2 2010).

- *Business case for sustainability.* With a few notable exceptions, most practitioners interviewed indicated that their companies view sustainability as a trend, an opportunity to reduce expenses in specific areas, a niche market, or a necessary measure to comply with new legislation (Roy 2000, McGuire 2010; Anon.2 2010; Liu 2010; Akman 2010; Russell 2010). Because there are few markets where sustainability is a selling point (McGuire 2010), managers do not see it as a primary driver of business value, and sustainable design practices are still often viewed as an unnecessary expense (Guven 2010).

  This lack of commitment to sustainability prevents management from allocating resources to the consideration of sustainability aspects during a product development process. Resulting time and resource constraints may make it difficult for design teams to adequately research materials and production techniques or learn how to use eco-design tools.

  When sustainability is not an overarching company strategy, design teams' attempts to consider sustainability may be limited to energy efficiency, resource efficiency, and other decisions related to production life-cycle (Roy 2000, Akman 2010; Bertolucci 2010; Guven 2010). However, when management embraces sustainability as a goal, design teams are afforded the extra time it may take to learn about new materials or production methods.

  When sustainability is embraced as an overarching company strategy, research and development of new, more sustainable technologies can actually drive new product development (Bertolucci 2010). And companies that have seen opportunity in working toward full sustainability have realized business profits. For example, Interface, a carpet manufacturer, sees sustainability as part of its "corporate DNA," and new designs are constantly measured against sustainability criteria (Bertolucci 2010). Interface-FLOR estimates that it has avoided $400m in waste costs as a result of their sustainability efforts (Anderson 2009).

  According to a corporate social responsibility (CSR) report published by BT, a telecommunications company, "customers who believe that BT takes its responsibility to society and the community seriously are 49% more likely to be very or extremely satisfied with BT" (BTplc 2009). By satisfying customer needs successfully, by practicing environmental stewardship, and by engendering trust through transparent corporate responsibility, businesses can ensure customer loyalty and positive brand association, thereby increasing market share and revenues through positive measures.

3.1.2. Success in product and PSS development

Pursuit of both innovation and sustainability can help an organization develop products and PSS that can help them gain or retain market share. Understanding that a healthy business relies on a healthy society, which in turn relies on a healthy ecosphere to thrive, we can generally understand success as "a product or PSS that innovatively satisfies business and customer needs within the constraints of the four sustainability principles." A vision of success for an individual product or PSS might include further elaboration on the basic business and customer needs that must be satisfied.

3.2. Strategies to bring products and PSS towards success

As mentioned earlier, the FSSD uses backcasting as an overarching strategy to provide directional context to solutions design. Backcasting can help design teams understand the gap between their current reality and their project vision, and use the resulting creative tension to brainstorm a wide array of actions that might draw them towards that vision (Robèrt 2000).

Once an organization decides to pursue innovation towards sustainability, backcasting may be used along with three additional strategic guidelines to help design teams prioritize actions and manage trade-offs in design decisions (Robèrt 2000).

3.2.1. Strategic guidelines

- *Move in the right direction.* To successfully innovate towards sustainability, design teams must be able to easily assess whether or not certain design choices will lead towards success. In the FSSD, moving in the right direction means using the four sustainability principles as guidelines to prioritize actions that do not lead to unsustainability (Robèrt 2000).

- *Build resilience.* To innovate, design teams must be able to able to manage risk, quickly recover from change and stay ready to seize new opportunity. The FSSD recommends building “flexible platforms” as a strategy that leads toward sustainability. This would help a company to avoid “blind alleys” that may not lead to future solutions (Robèrt 2000). In product development, rapidly changing technologies mean that products and services must be designed in a way that makes adapting to change less expensive (Kettunen 2009). Building resilience extends the idea of flexible platforms in that resilience allows a design team to explore new opportunities with the idea that they will discover and recover quickly from decisions that lead away from success. In addition, the attempt to develop PSS may create more resilient product portfolios than stand-alone products or services (UNEP 2001).

- *Provide business value.* In the FSSD, providing return on investment is a key strategy for success. The rationale behind this is that sustainability is best served when companies are able to pursue more sustainable measures in a way that keeps them profitable (Robèrt 2000).

  In a product design process that considers sustainability, a design team must be able to demonstrate return on the investment of consulting extra stakeholders and researching new technologies. Because innovation can directly help a business retain and increase market share, demonstrating how extra research can lead to innovation towards sustainability is important.

  Design teams and creative professionals are such a critical business asset in product and PSS development, that business value can also be gained by engaging employees in a process that empowers and motivates them (Melnik and Maurer 2006; Tessem and Maurer 2007).

3.2. Barriers and weaknesses in current design practices

Understanding barriers and weaknesses in current design practices, with respect to sustainability and innovation, can help to identify tools, concepts, and practices that may help a design team overcome those barriers to achieve their vision of success. This helps to answer research question 1.2, "Which tools, concepts, and practices from UCD, Agile, and Strategic Sustainable Development (SSD) can contribute to that success, and how?"

3.2.1. Barriers and weaknesses with respect to sustainability

- *Existing technology and materials are limiting.*
  Often, design teams run into barriers when theoretically possible sustainable measures are difficult to apply in practice. For example, the supply of certain "safe" materials may still be scarce, or material qualities may be incompatible with design requirements. Recyclability of certain materials is also still limited. (McGuire 2010; Guven 2010; Liu 2010)

- *Market research discovers customer preferences, not user needs.*
  Design teams may work with marketing teams to understand the "needs" of people by analyzing market research (Guven 2010). Marketing and design teams traditionally use methods such as surveys and focus groups to learn about user behaviors and preferences, but discovering unspoken needs with these methods is difficult. According to Patnaik and Becker, "these methods work well in quantifying customers' preferences among existing solution options, but they do little to identify the needs people can't readily articulate." To do this, companies must conduct deeper "needfinding" research (Patnaik and Becker 1999).

  There is little consensus about what "need" means in academic or business language. So the practice of needfinding could be limiting if the "needs" are understood as preferences, or "wants and desires." Market research is generally about preferences, and the rationale for those preferences, so it does not facilitate an understanding of human needs, or the needs of non-customer stakeholders. Moreover, the modern market does not demand products that satisfy human needs as much as it demands products that gratify wants and desires (Campbell 1998).

- *Mass production models inhibit dematerialization.*
  Mass production is one strategy that businesses use to maintain market share. When this is the case, machine production quotas may drive product development (Akman 2010), making the shift towards dematerialization difficult.

- *Limited systems view hides rebound effects and sustainability risks.*
  A design decision that seems beneficial in one aspect of a product's life-cycle may have negative impacts elsewhere in the life-cycle of a product. For example, recycling a certain material may consume more energy than it saves; or plastic water bottles designed for reuse may leach chemicals over time, threatening the user's health (Roy 2000). Products must be considered within society, within the ecosphere, and all of the stakeholders and components in the full system of a product, to understand the full impact of design decisions (Ny et al.2006).

3.2.2. Barriers and weaknesses with respect to innovation

- *Design teams tend to define solutions before context is fully understood.*
  In a workshop conducted to evaluate process ideas, the authors observed a strong tendency to plan the details of a design upfront, before the full context of the problem was understood. Many interviewees indicated that they did not have enough time to understand context upfront, before design requirements were defined (Guven 2010; McGuire 2010; Akman 2010). Designing solutions before understanding context may impede the design of new and innovative solutions.

- *The design dilemma inhibits innovation.*
  Traditional stage-gate design approaches are intended to minimize the likelihood of change late in the design process, when those changes might be more expensive (see Figure 3.1). However, more knowledge is built throughout the process, increasing the likelihood that new ideas will occur in later phases (Ullman 1992).

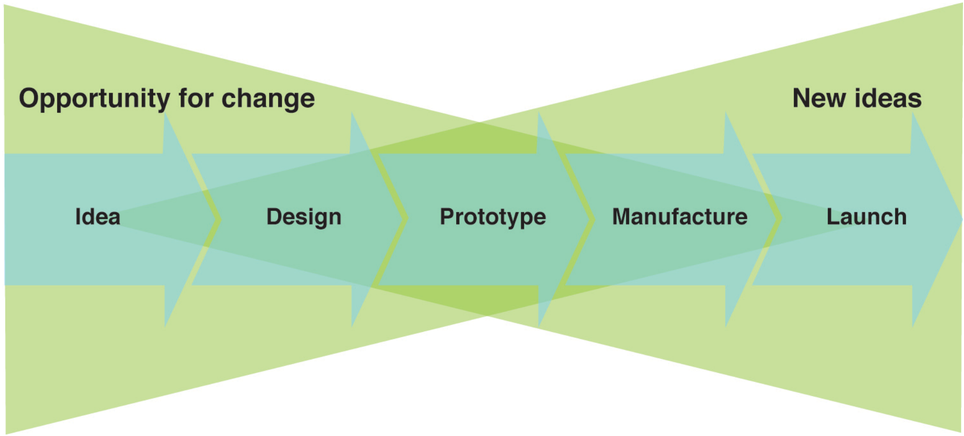

Figure 3.1. Diminishing opportunity for change.

- *Strong focus on physical products limits opportunities for PSS development.*
Physical products are still seen as primary value carriers to product companies, making it difficult for them to consider other interventions in the system that might provide opportunities to build PSS. Services are still seen as “aftermarket” activities (Larsson 2009). Even when products are designed without thinking of related services, services such as waste management and maintenance are provided by different stakeholders during a product's life cycle. When companies begin to focus on satisfying user needs with a combination of products and related services, they begin to interact with their users in new ways, improving relationships and forging tighter bonds (UNEP 2001, 11; Postaci 2010). When linked to marketing efforts, PSS development could lead to an increase in market share or open new markets for the company (UNEP 2001). PSS can lead to sustainability when sustainability is an explicit goal of the design process.

- *Organizational structures inhibit collaboration.*
Rigid hierarchies and disconnected departmental silos inhibit collaboration (Anon.1 2010; Stonehouse 2010; Si 2010), and some designers are not involved throughout the full product development process, from strategy through production (Daniel 2010; Liu 2010; Sun 2010). Separate “environment departments” are responsible for compliance with regulations, while Corporate Social Responsibility

(CSR) departments may work on green initiatives outside of core company operations (Anon.2 2010). This lack of collaboration between environment departments and product development teams within organizations leads to incremental improvement and does not support design teams effectively as they incorporate sustainability into their process (Gaziulusoy 2010; Postaci 2010).

Other barriers to effective collaboration include the secrecy of design processes or the extra expense of including all stakeholders (Stonehouse 2010; Gunnarsson 2010; McGuire 2010; Sun 2010).

3.3. Tools, concepts, and practices to support innovation towards sustainability

When using the FSSD to guide sustainable product development, a design team must first understand that they are working in a greater system that includes society and the ecosphere. They can then establish a vision of success that includes sustainability, and use the outlined strategies to help them to make appropriate decisions to prioritize potential design actions. Agile, UCD, and SSD can offer tools that will help them understand challenges and overcome barriers that threaten success.

The authors have identified barriers to success as a way to identify tools, concepts, and practices that may contribute to success by helping design teams to overcome those barriers. Each of those ideas is presented here, according to the strategy or strategic guideline that it supports in practice.

3.3.1. Backcasting from success

Agile methods can generally support a backcasting approach by supporting flexibility in solutions design as a team works towards that future vision of success. Agile expects change and places value in learning through process. For this reason, methods avoid detailed upfront planning and allow teams to work iteratively toward a high level goal. (Fowler 2005)

Keeping requirements “lean,” by including details only as they are determined to be necessary, supports the creation of a “principle-level” definition of success, as recommended by the FSSD.

3.2.2. Strategy 1 – Move in the right direction

The authors found two barriers and weaknesses in current practices with respect to the first strategic guideline.

- Existing technology and materials are limiting.
- Market research discovers customer preferences, not user needs.

There are several practices in SSD, and UCD that may help design teams to overcome these barriers.

- *Tools exist to guide sustainable product development. (SSD)* The MSPD, TSPDs and SLCA are tools developed by BTH and The Natural Step that offer guidance for sustainable product development. Other tools used by industrial designers, such as Solidworks, include an environmental dashboard that assists in life-cycle analysis.

  The MSPD includes detailed question sets that a can be used to investigate the sustainability aspects of product design. These questions use a full-systems approach and revolve around product function, product construction, material selection, production, and supply chain. These questions were designed in a modular way and may be consulted as necessary by design teams over the course of a product development process (Byggeth et al. 2007a). See Appendix E for a full list of sample sustainability questions.

  The TSPDs guide discussion between sustainability experts and company management to help quickly understand the overall sustainability consequences of product choices. They investigate product need, concept, and extended enterprise considerations using a life-cycle perspective (Ny et al. 2008).

  The SLCA is a simple matrix that maps the life-cycle stages of a product to the four sustainability principles. It is used as an alternative to a formal Life-Cycle Assessment (LCA) to quickly identify hot spots with respect to sustainability risks. Color-coding is often used to indicate level of risk, with green being low risk, and red representing high-risk areas that need attention. (The Natural Step 2010a)

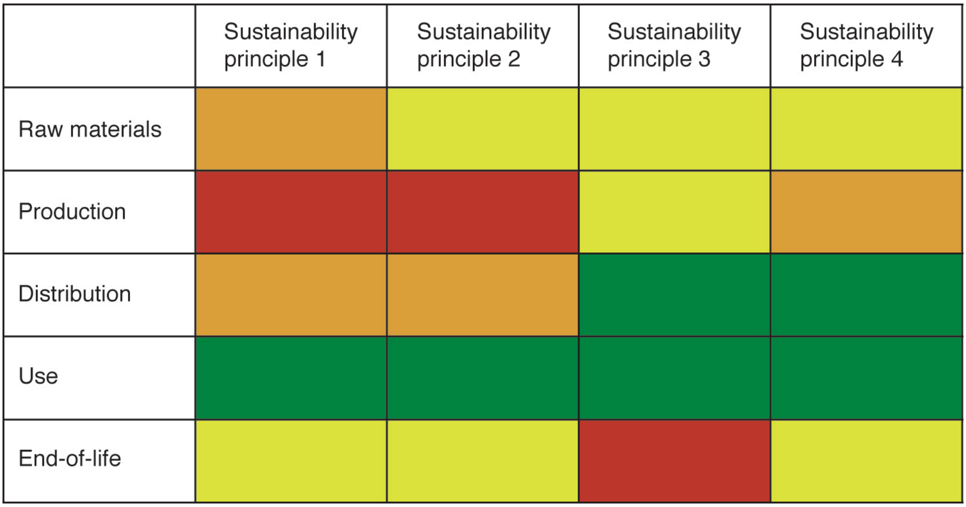

Figure 3.2. Sample Sustainability Life-Cycle Assessment

- *The four sustainability principles are useful as design constraints. (SSD)*
  SSD offers a definition of sustainability through the four sustainability principles. Using these principles as design constraints can inspire creative problem-solving. Between 2006 and 2009, AkzoNobel worked in collaboration with Forum for the Future and Carillion on the "Identification, Design and Delivery of Zero Emissions Paint Systems." The goal of this project was to develop a paint system without harmful emissions, and their first step was to establish a guiding vision for the project that included the four sustainability principles: "a completely sustainable paint system of the future." According to a case study published by Forum for the Future, this bold ambition "helped lead to greater leaps in thinking and producing tangible ... results." The shared vision helped to "guide decisions, stimulate creative and innovative thinking, clarify ambition," and reduce organizational barriers. (Forum for the Future 2010)

- *User research/Needfinding methods help discover latent needs. (UCD)*
  In user-centered design, needfinding seeks to discover user needs and recognize distinct motivations and barriers for different user groups. This is done with the idea that answering user needs will lead to a successful product or service. Its focus is different from

market research, in which the preferences of customers are researched. User research practices like ethnographic research, or observing users in their own environments, can take a significant amount of time, but are incredibly valuable (Brickstad 2010). Interviews with users can be quick or detailed, but require fewer resources than direct observation. The first part of IDEO's two-day "deep dive" workshop emphasizes field research, but offers a lightweight alternative to formal ethnographic research (Kelley 2001, Gavigan 2010). When time and budget are tight, shortcuts and lightweight research practices like interviewing customer service representatives or investigating online behavior may still provide useful information to consider in the design process (Lafreniere 2008).

- *Life-cycle mapping helps identify stakeholders and system components. (SSD)*
  Before conducting user research, design teams must identify potential users and stakeholders. In their project with AkzoNobel, Forum for the Future used a system map to "follow resource-flows through the paint life cycle – for carbon, waste and water. This helped identify the various ways in which raw materials and the final product were packaged and shipped between different stakeholders." In doing so, they identified the system boundaries of their product design process and began to identify their internal and external stakeholders (Forum for the Future 2010).

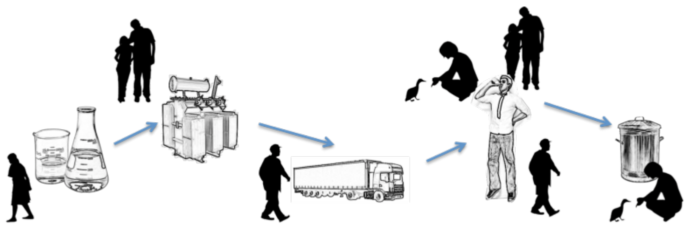

Figure 3.3. Life-cycle mapping of a product to identify potential user and stakeholders.

- *Manfred Max-Neef provides a definition of human needs and a clear understanding of needs and satisfiers. (SSD)*
  "Human needs must be understood as a system: that is, all human needs are interrelated and interactive. With the sole exception of the

need of subsistence, that is, to remain alive, no hierarchies exist within the system.” (Max-Neef 1991)

To consider human needs as part of a needfinding process, design teams require an understanding of human needs and satisfiers. SSD uses Manfred Max-Neef’s definition of needs and satisfiers to elaborate on the fourth sustainability principle. According to Max-Neef, basic human needs are finite, few and classifiable. These are same in all cultures and all historical periods while ways of satisfying these needs could change according to time, place and circumstances (Max-Neef 1991). Max Neef identifies the nine distinct human needs as: Subsistence, Protection, Affection, Understanding, Participation, Idleness, Creation, Identity and Freedom.

Max-Neef highlights the fundamental difference between “needs and satisfiers,” providing a clear ground to talk about products and services as satisfiers of needs. For example, when someone “needs new shoes,” the shoes are actually a satisfier. The need may be protection, identity, or participation, or a combination of all three. Since there is no “one-to-one” correspondence between needs and satisfiers, products and services can satisfy human needs in multiple ways.

- *Need maps and personas help design teams understand and empathize with users. (UCD)*
  Personas are developed through research to help design teams empathize with representative users. Persona documentation typically includes a name and photo, along with a short biography to help designers put themselves in a user’s shoes. It also usually includes key information about the representative user, describing his or her likely interactions with a product or service through drivers, barriers, needs, and use case scenarios. (Madsen and Nielson 2010; Spool 2008)

3.2.3. Strategy 2 – Build resilience

The authors found three barriers and weaknesses in current practices that relate to the second strategic guideline.

- Limited systems view hides rebound effects and sustainability risks.

- Design teams tend to define solutions before context is fully understood.
- The design dilemma inhibits innovation.

The following practices in SSD, UCD, and Agile may help design teams to overcome these barriers.

- *System mapping and causal loop diagrams help identify sustainability risks. (SSD)*
  Mapping the system is helpful to understand the dynamics of the causal relationships of the stakeholders as they are related to possible design decisions (Haraldsson 2004). This can help identify decisions that may inadvertently lead toward unsustainability (Byggeth et al. 2007), as well as opportunities for services and supplemental products to balance and strengthen the entire system.

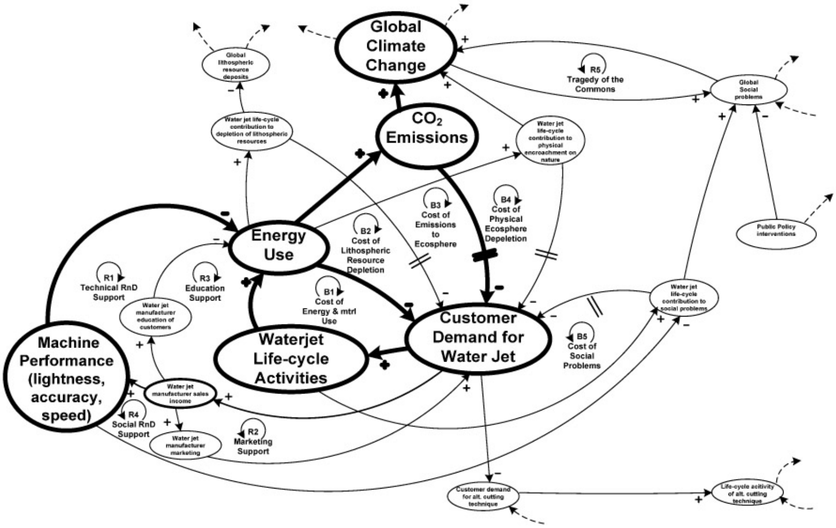

Figure 3.4. Causal Loop Diagram. Causal Loop Diagram with emphasis on how improved machine performance (e.g. reduced moving weight) could reduce energy use and thereby indirectly both (i) increasing customer demand for water jet cutting and (ii) decreasing CO2 emissions and its related contribution to climate change. (Byggeth et al. 2007)

- *Iteration 0 acts as a discovery phase to establish context. (Agile)*
  In traditional plan-based design approaches, an extensive upfront planning phase sets the stage for a project. However, this excludes

information about context that is learned over the course of the project. In Agile, a discovery phase often referred to as “Iteration 0” can help set just enough context to start a design team off with a shared understanding of the system. This discovery phase is intentionally kept brief, as understanding of the context is expected to develop as work progresses. (Shalloway, Beaver, Trott 2009)

- *Experience maps trigger new solutions. (UCD)*
  Experience maps describe the interaction of a user with a product or service, expanding on the distribution, use, and end of life phases of a product life-cycle (see Figure 3.5). Personas and experience maps may help trigger new ideas or validate proposed solutions.

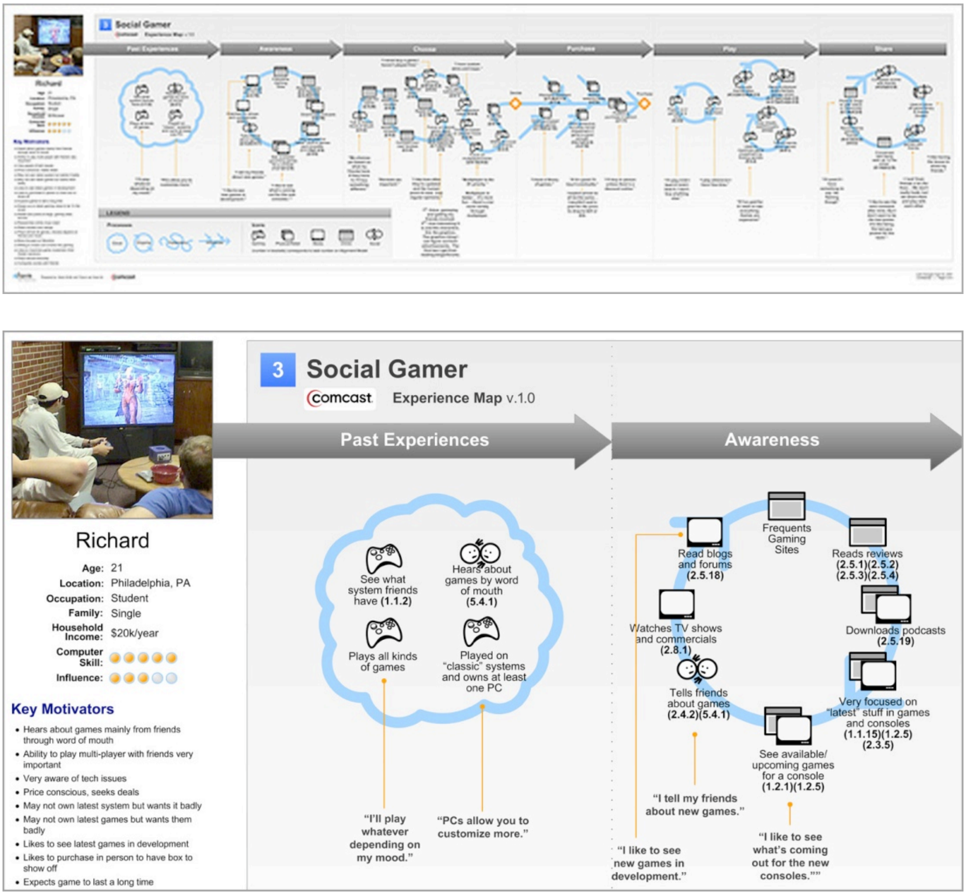

Figure 3.5. Full and detail view of Experience Map. (nForm 2010)

- *Backcasting from principles rather than scenarios helps to mitigate risk of changing circumstances. (SSD)*
  Describing success in terms of things that will not change, such as the sustainability principles or human needs, reduces the likelihood that changing circumstances will impact the success of a product or service (Holmberg and Robèrt 2000). Scenarios may easily be rendered obsolete by changing circumstances, and so using specific technologies or detailed requirements to describe success can be risky.

- *Lean requirements and functionality help keep flexibility in product design. (Agile)*
  Determining technical requirements for a product only as knowledge is gained minimizes the time spent on planning upfront requirements that may change later in a process. Lean requirements focus on building just enough functionality to satisfy user needs. In other words, a camera doesn't have to have a certain feature just because other cameras do. If no demand for that feature was detected during needfinding, there is no reason to develop it. Eliminating clutter in this way helps to keep designs flexible. (Kettunen 2009)

- *A process facilitator can help keep level of detail in check. (Agile)*
  Many agile methods assign one team member a facilitation role to help enforce the process. For example, in Scrum, this would be the Scrummaster. This role ensures that the agreed upon process is being followed, that the level of detail in proposed solutions hasn't moved ahead of the team's understanding of project requirements, or context, and that the team is regularly reflecting on what they've done, making necessary modifications to the process and product definition as they work. (Patton 2009a)

- *Continuous improvement in process and product design contributes to efficiency, quality, and quick response to change. (Agile)*
  Agile practices such as Kaizen advocate the concept of "continuous improvement," By regularly providing opportunities for reflection, they create strategic opportunities to change processes or products. When innovation opportunities arise, a company or design team should be prepared to embrace them. Likewise, when an idea fails in testing, design teams should be quick to learn from their

experience and either modify or release that idea. Learning organizations and cultures of trust are able to welcome and explore new ideas (Senge and Carstedt 2001), strengthening themselves through that process. For product companies, this culture of trust and exploration is important at the management level as well as the design process level. A rigid corporate culture, design process, or communication pattern might stifle innovation. (Anon.1 2010)

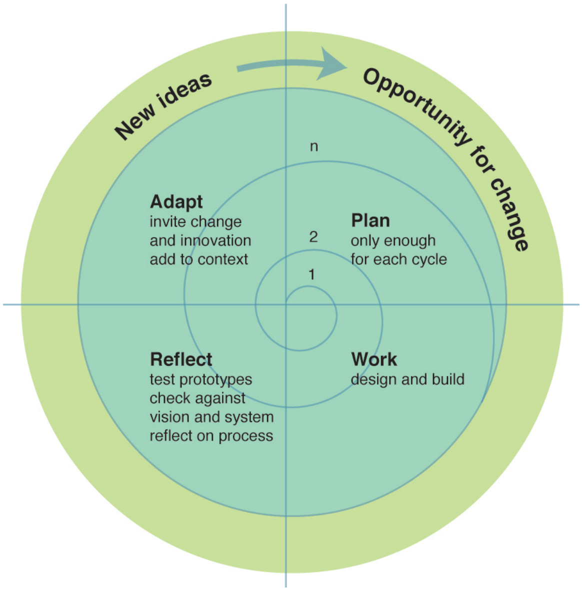

Figure 3.6. Continuous improvement through iterative cycles

- *Iterative work cycles mitigate risk. (Agile)*
  The idea of "working iteratively" simply means that a series of process steps are repeated multiple times to improve a product (Cockburn 2008). Many agile design teams use short, time-boxed iterative cycles, or "sprints" to manage product development (Fowler 2005). At the beginning of a project, the design team will decide how long a cycle should be (usually less than one month in software development). A certain amount of work is planned and completed within each cycle, and there is an opportunity to reflect on completed work at the end of the cycle. At this point, the team can decide whether to move forward with tested features or try a new direction. Multiple short sprints with regular reflection reduce the cost of failure, offering teams the opportunity to learn more through that failure.

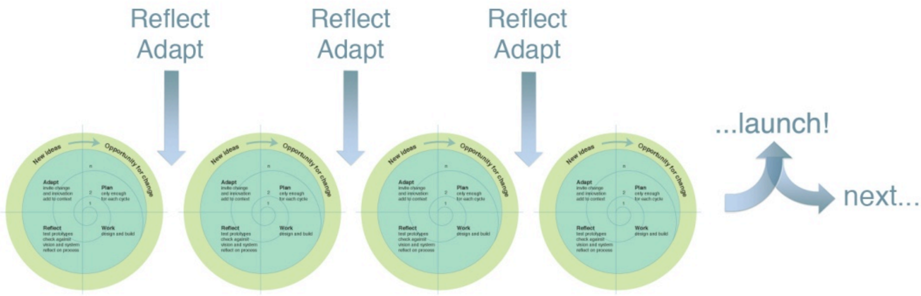

Figure 3.7. Iterative work cycles

- *Rapid prototyping mitigates risk and facilitates efficient communication. (UCD and Agile)*
  Rapid prototyping can bring efficiency to the design process and facilitate decision-making. Prototypes can be as simple as sketches or as elaborate as a functioning product that can be put into the hands of users and tested over a period of time. They can help team members, clients, users, and other stakeholders visualize and validate a product concept before major investments are made in manufacturing (McGuire 2010). Regular low-cost risk-taking and validation throughout the development process can lead to innovation. It should also result in a well-tested product that will be easily accepted by the market.

3.2.4. Strategy 3 – Provide business value

The authors found three barriers and weaknesses in current practices with respect to the third strategic guideline.

- Mass production models inhibit dematerialization.
- Strong focus on physical products limits opportunities for PSS development.
- Organizational structures inhibit collaboration.

The following practices and concepts within SSD, UCD, and Agile may help design teams to overcome these barriers.

- *Risk management and cost savings are being realized through eco-efficiencies. (SSD)*
  New environmental regulations provide incentives to minimize risk through sustainability. Some companies are moving towards eco-

efficiency practices because they see savings. They work with eco-design tools, check materials with databases, and try to use local and renewable resources as much as possible. Many design durable, timeless products that will not end up in landfills as quickly, thereby harming the environment less (Guven 2010; McGuire 2010; Breyman 2010). Manufacturing expenses can be reduced through environmental management strategies and practices that improve efficiency while reducing waste. Philips is a global manufacturer that has implemented eco-design practices to reduce cost and environmental impact. They project that their "Green Flagship" products will account for 30% of their total revenue by 2012 (Tukker et al. 2008).

- *Removing barriers to user modification eliminates need for multiple customized models. (UCD)*
  Innovation often occurs through user feedback or reinvention of a product (Ornetzeder and Rohracher 2006). Identifying barriers that may keep people from fulfilling their own needs can provide a key to product and service innovation. Accepting that a design will not be able to satisfy all needs frees a design team to focus on removing those barriers, facilitating product customization by end users.

- *Lean practices help with dematerialization, reduced cost of production, and reduced cost of change. (Agile)*
  The concept of working "lean," originally derived from Toyota practices, can generically be described as efforts to eliminating waste and surplus to improve overall value, whether in manufacturing or software development (Kettunen 2009; Fowler 2005). Lean, collaborative teams are composed of just enough key players to perform the job effectively, minimizing communication overhead and bureaucratic procedures (Kettunen 2009).

- *System mapping and causal loop diagrams help identify innovation opportunities, or leverage points. (SSD)*
  Mapping the system is helpful to understand the dynamics of the causal relationships of the stakeholders and system components as they relate to possible design decisions (Haraldsson 2004). This can help identify opportunities for making small changes in the system that have large positive benefits (Byggeth et al. 2007; Meadows 1999). (See Figure 3.2)

- *Experience maps trigger new solutions. (UCD)*
  Experience maps describe the interaction of a user with a product or service, expanding on the distribution, use, and end of life phases of a product life-cycle. Personas and experience maps may help trigger new ideas or validate proposed solutions. (See Figure 3.5)

- *Iterative cycles demonstrate value and invite innovation. (Agile)*
  Multiple short sprints with regular reflection and brainstorming provide opportunities to incorporate new ideas as more is learned about the system. The work resulting from an iteration may be a simple prototype or sketch, but it should be an artifact that demonstrates progress. Being able to demonstrate progress has many benefits. First, clients who have been asked to sign a contract with no detailed requirements may be mollified by visible progress. This allows them to give feedback and influence the direction of the project along the way, keeping their expectations in line with those of the rest of the design team (McGuire 2010). Second, if this prototype can be tested with users, they may be able to provide valuable feedback to influence the next iteration (McGuire 2010). And third, visible progress motivates the design team and gives everyone something to react to and reflect on (Melnik and Maurer 2006).

- *Agile methods support collaboration, facilitating innovation and reducing communication overhead. (Agile)*
  Agile methods are very people-centered with a focus on supporting teamwork over rigid process (Fowler 2005). They place high value on collaborative work, both for innovation and for efficient decision-making and problem-solving. In software development, importance is placed on having small, co-located teams that can share knowledge face-to-face rather than through extensive documentation.

  Building cross-functional teams brings deep knowledge from various project areas to the table. Including members of management, design, engineering, marketing, suppliers, and customers in design teams may help identify potential problems and opportunities more quickly. Interviews indicated that tight collaboration, and open communication amongst team members and between team members and management contributed to job satisfaction through efficient decision-making and knowledge sharing (Anon.1 2010; Anon.2 2010; Breyman 2010). An agile process can facilitate face-to-face collaboration opportunities and open lines of communication.

4. Discussion

4.1. Merging tools, concepts, and practices from UCD, Agile, and SSD into an innovation approach

After understanding the key strategies for success in innovation towards sustainability, and after identifying the tools, concepts, and practices from UCD, Agile and SSD that might help design teams overcome common barriers to success, the authors were able to see how UCD and Agile tools, concepts, and practices could be brought together in support of SSD as part of an innovation approach for sustainable product and PSS development.

UCD tools and practices can support SSD by contributing to an understanding of the full system of a product or service. Agile practices provide a practical way to manage a design process in a complex system while supporting innovation and collaboration. The authors propose a recommended innovation approach that combines relevant tools, concepts and practices from all three fields to answer this study's primary research question, "How can design practices drawn from Agile and User-Centered Design (UCD) support innovation as design teams work strategically towards sustainability through product and PSS development?"

4.1.1. Supporting SSD with UCD tools and practices to establish a full systems context

UCD practices bring value to product and PSS design/development by shifting the focus of design from market preferences to user needs. The authors also believe that UCD practices can supplement existing SSD practices by strengthening the application of the fourth sustainability principle within product and PSS design.

The fourth sustainability principle states that we should work to remove barriers that keep people from meeting their basic human needs. When it comes to designing products and services, we must consider the needs of all people involved in the full system of a product, that is, everyone who may be affected at any point along a product's life-cycle. The TSPDs invite practitioners to consider both the market needs and human needs that are satisfied by a given product, along with the current and potential extended enterprise of the product. The TSPDs are designed to facilitate communication between sustainability practitioners and business managers

(Ny et al. 2008). While they introduce the idea of human needs into product development, they are not intended to support design teams in discovering user needs or considering them throughout a design process. This is the value that UCD practices can add to current SSD practice.

From a life cycle perspective, UCD typically focuses on the needs and behaviors of "users" during the "use" period of the product, so it lacks a full system view. The authors of this thesis believe that UCD can support sustainable product development when needs research is extended to include non-customer stakeholders along the whole life cycle of the product or service.

Another weak point of UCD is that while it provides tools focused on discovering and answering user needs, the definition of "needs" is not very clear. Within UCD, "needs" are often described as desires or functional requirements, without attention paid to deeper human needs. To resolve this, and make UCD useful within an SSD context, UCD practice may be bolstered with Max-Neef's categorization of human needs and concept of satisfiers.

Identifying stakeholders. In SSD, a design team might begin by mapping out the life-cycle of a product to discover all of the stakeholders in a product's system. UCD practice could then be applied to map the experience of each stakeholder along the life-cycle with respect to his or her interaction with the product. These experience maps could, in turn, identify further system components and stakeholders.

Stakeholders may include internal teams/departments, supply chain actors, customers and non-customers. Design teams typically consider only customer and business needs as a part of their process. Extending the system to include non-customer stakeholders requires design teams to consider user needs in the context of human needs and to consider solutions that do not create barriers for any stakeholders as they seek to meet those needs.

Products and services as satisfiers. As they are designed today, products and services seek to satisfy peoples' wants, and must fulfill certain functional requirements, but they do not necessarily take fundamental human needs into account. In 1971, Victor Papanek, a designer, educator, and strong advocate of socially and ecologically responsible design, wrote, "Much recent design has satisfied only evanescent wants and desires, while the genuine needs of man have often been neglected by the designer. The economic, psychological, spiritual, social, technological, and intellectual needs of a human being are usually more difficult and less profitable to satisfy than the carefully engineered and manipulated 'wants' inculcated by fad and fashion" (Papanek 1971). When we analyze this statement from Max-Neef's perspective, we can say that there could be "false/pseudo" satisfiers, which stimulate a false sensation of satisfying a given need. Fashion and fads may seem to satisfy the basic need of identity without actually doing so. A satisfier that over-satisfies one need while inhibiting the possibility of satisfying other needs is considered an "inhibiting satisfier." Products or services that satisfy a need without a negative effect on others are called "singular satisfiers," while those that satisfy multiple needs without a negative effect on others are called "synergic satisfiers" (Max-Neef 1991). To reach sustainability, design teams must strive to design either singular or synergic satisfiers.

Table 4.1. Classification of satisfiers (Max-Neef 1991).

Satisfier	**Description**
Destroyer	Destroys the possibility of satisfying a given need over time and impairs the satisfaction of other needs
Pseudo-satisfier	Generates a false sense of satisfaction
Inhibiting satisfier	Over-satisfies one need, thereby inhibiting satisfaction of others
Singular satisfier	Satisfies one need without consequence for others
Synergic satisfier	Satisfies one need while contributing to the fulfillment of others

Mapping needs. Recognizing products as satisfiers of human needs is critical to product development that leads toward sustainability. According to Roberto Verganti "User-centered innovation has helped conduct us into an unsustainable world." He argues that design-driven innovation is the answer. (Harvard Business Review 2010) The authors of this thesis believe that the answer lies in distinguishing between "preferences," "functional requirements," and "human needs" within the design process and then ensuring that human needs are explicitly considered.

Marketing teams may place importance on preferences, tracking trends with the goal of increasing their revenue, while user-centered design teams consider both user preferences and functional requirements as they develop products. Business needs are met by fulfilling both the functional requirements and preferences of customers in a product or PSS. Considering human needs in addition to preferences and functional requirements would both strengthen a product offering and reduce sustainability risks for a business.

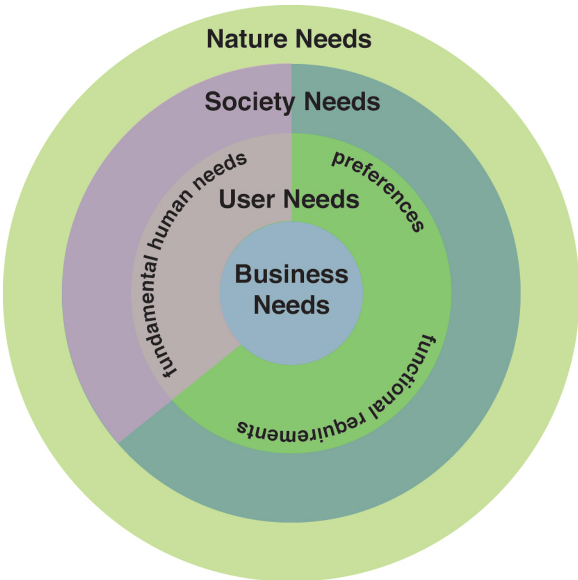

Figure 4.1. Nesting business needs within user needs. User needs consist of fundamental human needs, preferences and functional requirements. User needs are nested within society needs within nature needs for a full systems perspective.

As an example of the dynamic between these needs, consider a water bottle. Halle, a representative user, wants a stylish water bottle that she can clean easily, and carry around in her backpack. From this statement, we can discern that she desires something stylish (a preference), which is portable (functional requirement), small enough to fit in a standard backpack (preference), water-tight (functional requirement), and washable (functional requirement). By its nature, a portable beverage container satisfies the basic human needs of freedom and subsistence. Once this is understood, products and services may be designed to satisfy these needs without damaging the environment or impacting other human needs negatively. For example, if the water bottle were made from plastic, chemicals may leach from the plastic into the beverage, affecting Halle's health and violating her need for protection, another basic human need.

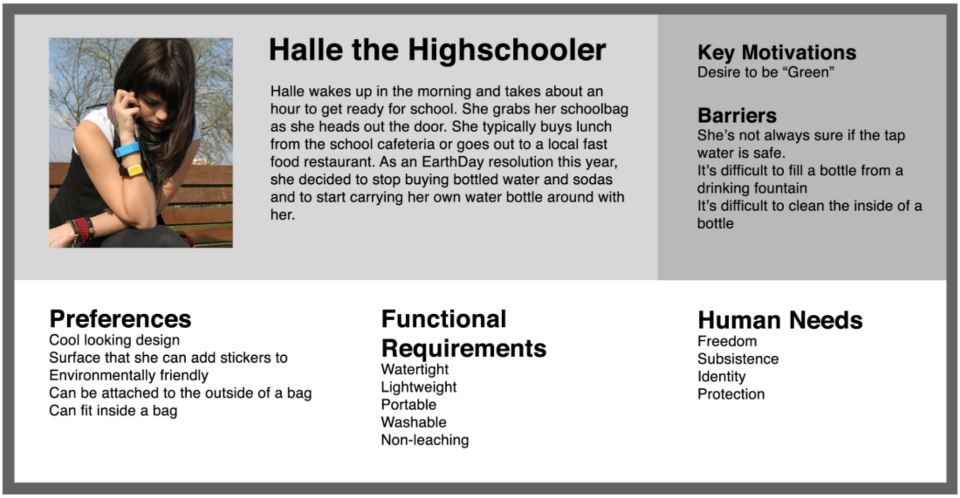

Figure 4.2. A sample need map for a persona/representative user.

Mapping barriers along with needs is also helpful. Identifying barriers that keep people away from meeting their own needs could provide a key to PSS innovation and may provide business value while furthering sustainability.

Designing satisfiers. UCD practice includes tools to find needs and to help design satisfiers through regular testing and observation of real users. Needfinding is an exploratory process, while designing satisfiers is a creative process. Once needs are identified and classified appropriately, satisfiers must be designed to fulfill those needs sustainably.

Creating satisfiers to meet user needs in a sustainable way is a very complex task. Need maps and system maps can help a design team understand connections across the system and will help to identify those singular and synergic satisfiers that won't have negative impacts on human needs across stakeholders. It is also important to remember that a healthy society is dependent on a healthy ecosphere, and that user needs should be met without violating the first three sustainability principles. SSD brings the tools into this creative process to examine needs with a systems perspective and check potential solutions against all sustainability principles.

4.1.2. Supporting SSD with agile practices to manage the design process

Managing complexity while supporting resilience. SSD practices offer a systems-based approach to sustainable development. Stakeholder engagement is recommended across the system and the FSSD, or the Natural Step Framework, is offered as a way to build consensus between stakeholders at a principle level and to manage strategic decision-making in complex systems. The FSSD uses backcasting from principles as a strategy to guide decisions toward sustainability. This is to avoid the implicit risk of running into dead ends while working towards scenarios that may be subject to change. Similarly, agile methods acknowledge that the future is subject to change. While backcasting is not explicitly employed as a strategy in agile methods, success is carefully phrased as a solution to a problem within a context rather than as a detailed specification. Required details of tasks that will lead towards a solution become clear as context is better understood over the course of the design process.

The FSSD employs the strategy of building “flexible platforms” to prioritize measures that can serve as “stepping stones” to a sustainable future vision. Through lean design, short iterative cycles and regular reflection and adaptation, agile methods increase the likelihood that nearly any measure can serve as a flexible platform. While plan-based approaches create a brittle design process that makes it difficult to incorporate late-stage changes, agile methods regularly solicit feedback and incorporate change through small, inexpensive steps. The concept of Iteration 0 may be used as a discovery phase to start building an understanding of context through system mapping. Building on that contextual understanding through each iterative cycle and making detail-level decisions only as understanding is gained increases the likelihood that decisions will not lead into dead ends.

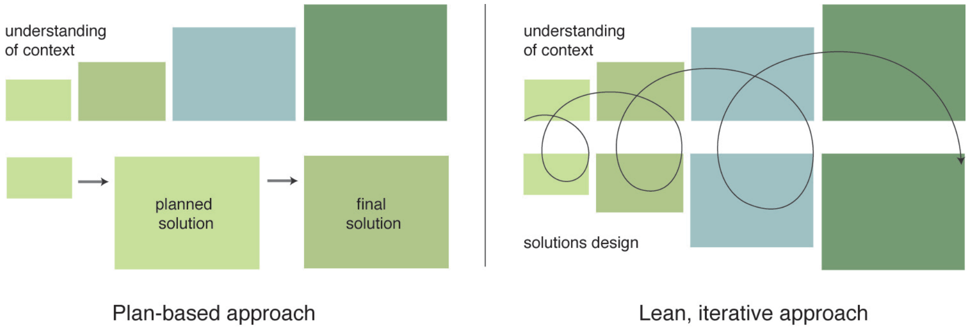

Figure.4.3. Benefit of designing solution detail only as context is understood

Eco-efficiency measures are not sufficient to bring our society to full sustainability. More innovative steps must be taken to reach that goal (Roy 2000). Agile processes that reinforce regular consideration of the system while minimizing the risk involved in pursuing opportunity can support innovation.

Managing collaboration. In sustainable product development, collaborative partnerships must be managed across supply chains and through the end of a product's life. Decisions concerning materials choice, manufacturing strategy, user experience, and overall business strategy have implications across the system and can be most efficiently handled through open collaboration within a cross-departmental team of experts.

Agile methods place emphasis on collaboration over documentation, and explicitly support teamwork and partnership management, placing high value on building and harnessing the expertise of individual team members to support innovation and efficiency. A 2006 study showed a significant increase in job satisfaction and motivation in agile development teams over non-agile teams. A related study in 2007 verified that job satisfaction and motivation were high even in a large agile team. These studies found that the ability to influence decisions and close relationships with users were two statistically significant benefits of agile over non-agile processes. (Melnik and Maurer 2006; Tessem and Maurer 2007)

Regular meetings and transparent communications practices in Agile build trust among team members and other stakeholders. In, "Innovating Our Way to the Next Industrial Revolution (2001)," Peter Senge and Göran Carstedt point out that, "people who are co-innovating must know and trust each other – in ways unnecessary in traditional relationships between providers and customers … all the big steps in design for remanufacture require intense cooperation up and down the supply chain." To consider an "ecology consisting of products, spare parts and services," as PSS design demands, the relationships between the parts have to be understood and managed in order to achieve a harmonious result. The direct collaboration of all stakeholders makes it possible to innovate together with shared information, experience and expertise. Thus, agile design practices that support trust and cooperation are well-suited to support supply chain management, take-back programs, and sustainable PSS development.

A similar approach is practiced at Volvo Technology VTEC, the center for innovation, research and development in the Volvo Group. They collaborate not only within Volvo Group, but also with infrastructure stakeholders, and selected suppliers. They also participate in national and international research programs involving universities, research institutes and other companies (Wirmark 2009).

4.1.3. Merging UCD, Agile, and SSD to support innovation towards sustainability

Table 4.2. Merging strategies, methods and tools to support innovation

	SSD	**UCD**	**Agile**
Strategy 1 – Move in the Right Direction	4SPs MSPD SLCA Life-cycle System Map Definition of Human Needs and Satisfiers	Needfinding Need Maps/ Personas	Iteration 0/ Discovery
Strategy 2 – Build Resilience	CLD System Map	User Testing	Iterative Work Iteration 0/ Discovery Rapid Prototyping Continuous Improvement Lean
Strategy 3 – Provide Business Value	Leverage Points Eco-efficiencies	Experience Maps User Testing	Iterative Work Collaborative Work Lean

For optimum success, UCD, Agile, and SSD tools and concepts may be used together in a way that strengthens potential for innovation toward sustainability in product and PSS design. Between the three approaches, where one does not address a critical strategy, another will. The authors propose the following approach that combines the strengths of each practice, establishing a solid understanding of the system and encouraging innovation through regular reflection and expansion of that understanding.

Iteration 0 - Discovery and project kickoff. There are two main tasks in a design project; one is to understand the context of a design problem, and the other is to design a solution. At any point in the project, the level of detail in a proposed solution should be in step with the design team's understanding of context (Patton 2010). Assuming that greater understanding will be gained over the course of a project, the goal of this discovery phase is to learn just enough to get the team started. System maps and needs definitions may then be developed or modified along the way.

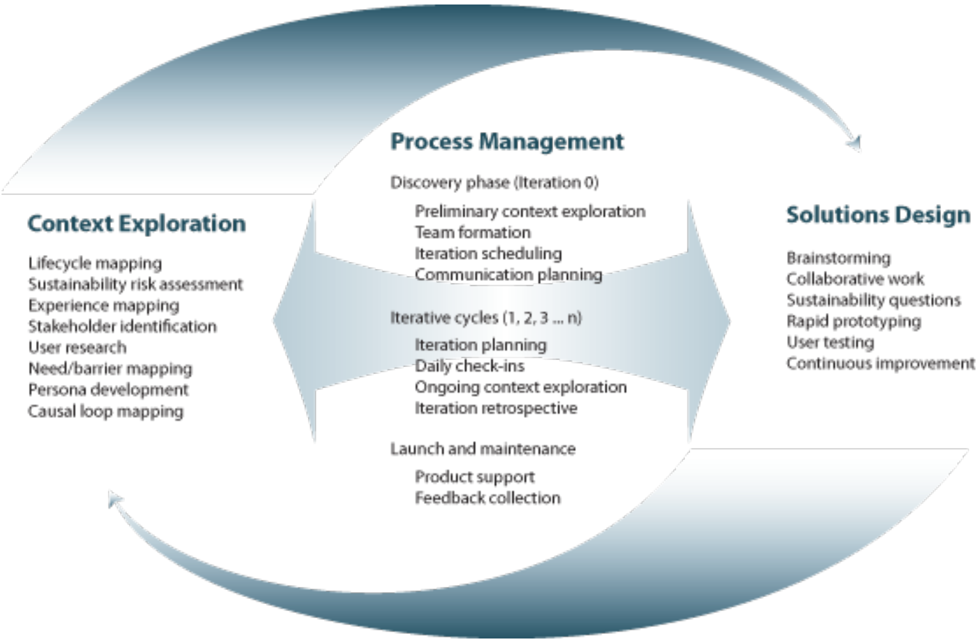

Figure.4.4. An innovation approach towards sustainability in product and PSS design. Process management techniques borrowed from agile methods support context exploration and solutions design.

Administrative details, such as team formation, communication structures, and iteration timelines are also taken care of in this pre-planning stage.

- *Map the system*
  - *Identify life-cycle components, stakeholders, and experience elements.* Sketching a life-cycle map of the existing or potential product may identify potential supply chains, manufacturing operations, distribution mechanisms, stakeholders, end-users, and end-of-life disposal or take-back options. Including any components of each life-cycle stage that are already known, such as elements of the user experience at each life-cycle stage, will help extend the design team's understanding of the full system.

  - *Identify sustainability risks.* Using an SLCA matrix to perform a quick, high-level analysis of product life-cycle aspects with regard to the four sustainability principles may identify high-risk areas of focus.

  - *Add causal loops and identify leverage points.* Identifying causal loops in the system map may reveal leverage points and potential rebound effects of the products or PSS being designed. If causal loops and leverage points are not obvious at the beginning of the process, they may be identified later as more is understood.

- *Conduct preliminary needfinding and map needs.* The discovery phase offers an opportunity to begin needfinding research on all known stakeholders. To support a shared understanding of the system, the full design team may participate as directly as possible in user research.

  As described earlier, there are several lightweight user research practices that may be applied within whatever time and budget is available. User testing and further research may be conducted over the course of the project, as necessary. New users and stakeholders may also be added as the system map develops.

  There are two distinctions between classic user-centered design practices and the recommendations in this approach:

- To guide a design process towards sustainability, user research must include non-customer stakeholders. This includes anyone who is impacted within the system along the life-cycle of the product.

- To create a clear understanding of needs and potential satisfiers, the authors recommend developing personas for each distinct user segment and mapping representative needs and barriers at three distinct levels - preferences, functional requirements, and basic human needs.

- *Agree on success and initial goals.* The discovery phase provides the opportunity for a design team to begin with a shared definition of sustainability and a high level vision of the project's success. A lean vision would include only those constraints that are absolutely necessary, and avoid outlining functional requirements at a level of detail. Including the four sustainability principles in the project vision provides high-level design constraints that can guide the project towards sustainability.

  Artifacts that set context, such as the system map, the SLCA, and any outcomes from the needfinding process, may be used to identify areas of focus and spark ideas for potential solutions. The level of detail in the proposed solutions should not exceed the design team's understanding of the system and context of the challenge.

  Potential measures outlined in the brainstorm may be prioritized using three criteria:
    - Does it move us in the right direction?
    - Does it build resilience?
    - Does it provide business value?

Once a main idea has been selected, high-level project elements may be identified. In Scrum, one agile methodology used in software development, tasks take the form of "user stories." Major tasks are often referred to as "epics." If the scope of the project is very large, an epic may describe the goal of a release cycle, and user stories may be broken down to fit into each time-boxed iteration.

- *Build collaborative teams and partnerships.* Everyone critical to the process is a part of the design team - engineers, chemists, industrial designers, marketers, user experience practitioners, supply managers, strategic managers, clients, and partners. While lean teams keep communication overhead low, it is important that all project stakeholders are routinely kept in the communication and decision-making loop. End-users are not always a formal part of the team, but would be consulted as regularly as possible throughout the product development process.

- *Agree on the process.* Following a specific process is not as important as making sure that everyone is aware of and comfortable with the process. Processes themselves are likely to change in the course of the project, as the team determines what helps them work most effectively. In general, this approach recommends that teams work in iterative cycles and that the process should provide enough structure to keep a project moving along on schedule. Iteration cycle length and communication methods should be agreed to upfront, but may be adapted as necessary over the course of a project.

    - *Iteration and release cycles.* Plan iteration cycles, or sprints, according to the scale of the project. Sprints should be long enough to give the design team time to provide something of value, such as a prototype that may be tested with stakeholders. They should also be short enough to manage risk and encourage innovation with regular reflection and adaptation. Two to four week cycles are considered normal in software development, although longer or shorter cycles are used if necessary. More formal releases of high fidelity prototypes may be planned along the way to test the outcome of multiple sprints.

- *Team communication patterns.* Regular and transparent communication between team members, including key stakeholders, is important to this approach. Daily check-ins, iteration planning meetings, and iteration retrospective meetings facilitate communication. Co-location of team members and use of collaboration software can also encourage efficient and transparent decision-making. Trust supports innovation, and so functional communication pathways are critical.

Iterative work cycles - Repeated until product launch

- *Plan for this iteration.* At the beginning of each iteration, an iteration planning meeting offers an opportunity to map out stories for the iteration. Following the rule of defining requirements only as they are understood, these stories would include detailed specifications only when necessary to the success of the iteration. Tasks are phrased as user requirements ("a user will be able to bring a beverage with him as he runs errands") rather than detailed technical requirements ("build a reusable water bottle with a screw cap"). This helps design teams understand the context of the requirement and allows creative problem solving.

  In the iteration planning meeting, the design team would decide how many tasks can be accomplished in the given time, and what results they will be able to test and demonstrate to stakeholders by the end of the iteration. All stakeholders would be involved in this meeting, giving clients and project owners an opportunity to weigh in on team priorities.

- *Work collaboratively with sustainability as a goal.* When all stakeholders are included as members of the design team, and the process involves everyone from the beginning, there is a shared understanding of the system, needs, barriers, and opportunities. From there, work can be conducted independently with opportunities for regular collaboration.

  All available stakeholders are involved in planning and reflection meetings at the beginning and end of each cycle. During a cycle, daily stand-ups, or short 5-10 minute meetings, allow team members to check in with each other. In these meetings, each team member reports what they did yesterday, what they plan to do today, and what might be keeping them from performing their work, or "blockers."

Co-location of design team members facilitates efficient problem solving and decision-making. Collaboration with off-site customers and non-customer stakeholders may be managed by exposing ideas online for participation and feedback. Low-fidelity prototypes can facilitate discussion and feedback as well. Additional needfinding may be conducted during each iteration, as it becomes necessary.

The sustainability question modules from the MSPD may be used to guide design decisions with respect to sustainability at any time in the process.

- *Reflect*
    - *Reflect on progress*. During an "iteration retrospective" meeting, the design team may demonstrate progress made during the last iteration to all stakeholders for feedback. The team would reflect on what they've learned in the course of the iteration. This meeting provides an opportunity to review and modify the system map, experience components, needs map, and SLCA, making any required changes or additions based on new knowledge.

    - *Reflect on process*. During reflection, the design team might discus recurring blockers and pace of work, noting where the process has been difficult to follow or insufficient to support their work. Completed stories may be compared with planned stories to evaluate the accuracy of workload estimation.

- *Adapt.* After reflection, design teams discuss desired changes to the process or product design. The concept of continuous improvement involves asking:

    - What will you keep doing?
    - What will you stop doing?
    - What could you do better?

During the iteration retrospective meeting, the design team might identify new ideas to try out in the following iteration. A quick brainstorm may reveal any new opportunities revealed by an updated system map, needs map, or SLCA, including new partnerships or services that might support the system.

Launches and portfolio planning

Where product development is concerned, product portfolios can be planned around stepping stones toward sustainability, ensuring that the company is moving steadily in the direction of their vision. System maps and need maps developed over the course of the project may have revealed opportunities for services to supplement physical products in ways that advance the company towards its sustainability vision.

To continually improve on a product or PSS, a support phase may be used to gather feedback on a launched product. The design team may decide on an approach to maintenance cycles and communication paths to collect feedback from stakeholders and customer service representatives during a "project retrospective" meeting. Products may be monitored over time to identify any negative rebound effects that may contribute to un-sustainability in ways that were not anticipated. Actively supporting a product and collecting customer feedback after launch may also make it easier to incorporate new technologies that were not available when a product or service was first launched.

4.2. Key findings

Key findings about UCD tools, concepts, and their application within SSD, explain how UCD could be extended to strengthen application of the fourth sustainability principle within product and PSS development. Key findings about agile tools, methods and practices explain how these could be applied within SSD to support backcasting, continuous improvement towards sustainability and collaborative cross-functional teamwork. The key findings indicate that UCD tools and agile methods can support the full systems perspective necessary in SSD and innovation towards sustainability in product and PSS development.

4.2.1. UCD processes can contribute to innovation for sustainability when human needs and non-customer stakeholders are considered during the design process.

UCD contributes to innovation by exposing and exploring the needs of users. However, current practices typically only consider the “end-users” and the “use” period of a product or service, and lack the full systems perspective necessary in design for sustainability. This full systems perspective would include the full life cycle of products or services and all non-user stakeholders across that life cycle. It also lacks a robust definition of “need.” By strengthening existing UCD practices with a full systems perspective and Manfred Max-Neef's robust definition of needs and satisfiers, they can contribute significantly to innovation for sustainability.

4.2.2. UCD can strengthen the application of the fourth sustainability principle within product and PSS design.

The 4th sustainability principle within SSD broadly states that we should work to eliminate barriers that keep people from meeting their needs. As products and PSS are generally designed with the intent of creating solutions to satisfy people's needs, this principle is a natural focus of the design process. UCD techniques can help design teams to distinguish between user groups and then map barriers, preferences, functional requirements, and human needs for each group, as the authors suggest in this study. These practices strengthen the practical application of the fourth principle during product and PSS design.

4.2.3. Agile methods can support a backcasting approach to design flexible platforms.

The FSSD uses backcasting from principles as a strategy to guide decisions toward sustainability. This is to avoid the implicit risk of running into dead ends while working towards scenarios that may be subject to change. While backcasting, one goal is to design flexible platforms that can be built on and used as “stepping stones” to reach a sustainable future vision. Agile practice is built on the assumption that circumstances will change; therefore project success is carefully phrased as a solution to a problem within a context, rather than as a detailed specification. Agile methods such as lean design, short iterative cycles, and regular reflection and adaptation, increase the likelihood that design solutions will serve as flexible platforms.

4.2.4. A time-limited discovery phase (Iteration 0) supports consideration of a complex system.

While agile software development methods do not always include a discovery phase before beginning iterative design cycles, a shared understanding of the full system and sustainability risks is necessary when designing products for sustainability. A short, high-level discovery phase can accomplish this. The time spent on upfront context research should be limited, acknowledging that more will be learned through design over the course of the project.

4.2.5. Agile can support innovation for sustainability by reinforcing reflection and consideration of the system.

Literature studies and expert review confirmed that mapping and visualizing the full system of a product, including life-cycle and stakeholders, is critical for sustainability and innovation. Because it is difficult to understand the full system upfront, and because understanding the system is so critical to designing solutions, iterative cycles can reinforce regular reflection on and modification of system maps.

4.2.6. Switching to agile methods involves an initial learning curve.

Current product development processes are typically plan-based and stage-gate rather than Agile. From the workshop and interviews conducted, the authors learned that when teams work with an agile approach for the first time, they might feel unfamiliar with the process and have difficulty working within iterations. There may also be a strong urge for design teams to plan details upfront, before context is understood. When organizations begin working with Agile, it is important for management to remember that Agile is a value system rather than a prescriptive process. These values must be embraced by the organization as a whole to effectively support design teams, and structured flexibility in organizational process is as important as it is on a project level. While there may be an initial learning curve for organizations and design teams when adopting an agile approach, once adopted, agile methods may increase efficiency, product quality, and employee satisfaction. A key finding of this study is that there is a need for some preparatory education before design teams start working with an agile approach. Some agile methods also assign a coach or facilitator role to keep iterations on track and to ensure that detailed planning does not get ahead of understanding.

4.2.7. Cross-functional teams that transparently include project stakeholders contribute to innovation for sustainability.

Current product design teams consist mainly of industrial designers, who regularly engage in cross-disciplinary collaboration in the course of their work. They communicate with marketing teams, production departments, engineers, management, and supply chain managers and are responsible for gathering all data necessary to their work. However, they run into barriers mainly due to this divergent structure that they are functioning within. One important key finding of this study is the concept of cross-functional "design teams" to integrate different departments in the design team with representatives from each and consider users and all stakeholders as much as possible during the design process. The diversity in the design team will bring effective and efficient collaborative work within the agile structure. The authors of the thesis found that a cross-functional design team could help integrating sustainability principles into this process effectively.

5. Conclusion

5.1. Summary and implications of key findings

The authors saw value in investigating UCD practices because they consider user needs along with business needs, rather than focusing simply on market trends. This needs-driven approach seemed to fit well with SSD, and so they explored the potential of using UCD methods to discover and consider fundamental human needs as part of a design process.

The UCD practices recommended in this approach are user research, need-mapping, persona development, experience mapping, and user testing through rapid prototyping. The authors have found that these practices may help design teams understand the context of the full system when applied to all stakeholders along the life-cycle of a product. The authors recommend researching and documenting needs and barriers for all users on three levels - preferences, functional requirements, and human needs. The traditional understanding of user needs in UCD practice must be supplemented with a clear definition of human needs to lead a design process towards sustainability, especially in consideration of the fourth sustainability principle. UCD practices should be employed in support of sustainability in product and product service system development, as they can strengthen application of SSD concepts by increasing understanding of stakeholders as well as end users.

The authors also saw the potential success of combining Agile and SSD approaches to manage design for complex systems, and explored this thoroughly in their research. Common agile values and process practices fit perfectly into a strategic approach towards sustainability when combined with the tools and methods provided by SSD.

The authors recommend using an iterative agile approach with a brief discovery phase to manage the design process. Agile methods can support a backcasting approach, facilitating the design of flexible platforms that can be adapted as circumstances change. The discovery phase and regular reflection opportunities during iterative cycles help to manage work within a complex system, as design for sustainability demands.

The move from plan-based, stage gate design processes to agile methods may require an initial investment in training, and the benefits in efficiency may not be immediately apparent until the initial learning curve has passed. However, agile methods have such potential for creating the conditions for sustainable innovation and for providing business value that the authors strongly suggest that they are considered as a strategy for organizations that wish to move towards sustainability in product and PSS development.

Tight collaboration between internal departments, management, partners, and users promotes efficient problem solving and creation of innovative solutions. Transparent, non-hierarchical communication structures can promote trust and support this collaboration. Agile methods value team members and collaboration over specific process guidelines and focus on creating opportunities for regular, but highly efficient meetings and communication. As solving the sustainability challenge requires teams to innovate and find new ways of doing things, methods that support collaborative work, pulling expertise from many areas and reinforcing a shared vision of the system, are important to design for sustainability.

5.2. Recommendations for future research

In an ideal application of the recommended approach, design teams will use UCD and SSD practices to understand the system while working toward sustainability. Agile processes will promote transparent cross-departmental collaboration and help design teams to regularly consider the full system of products: life-cycle components, services, the needs of all stakeholders, and the barriers they encounter when trying to meet those needs. The organization itself will benefit from this and become more resilient, potentially making changes to create value through service development, as a supplement to physical product development. The more sustainability is considered using this approach at a design project level, the more it will take hold as a value in other parts of an organization. The authors see potential for this product development approach to lead to the sort of conditions where senior managers will begin to consider sustainability part of the DNA of their organizations rather than the separate domain of CSR departments.

While expert reviews indicate that the elements included in our approach are helpful and practical in the design process, action research could be used to apply the recommended approach and discover which aspects provide critical value in practice, and which aspects proved problematic.

Specifically, the authors would recommend further research on the effectiveness of need and barrier mapping at each recommended level; human needs, preferences, and functional requirements.

Several expert reviewers commented that this approach could inform broader organizational strategy, beyond product and PSS design. This investigation was somewhat outside of the scope of our research, but may be a promising new study.

It may also be worthwhile to research which sectors within product development would find this approach most practical. The authors conducted interviews from a wide range of sectors but could not draw any strong conclusions about where the approach would be most effective.

There have been studies about how to create and sustain shared mental models in big organizations. Agile methods have also been used successfully in both large and small teams. Because it is necessary in this approach for design teams to continuously reflect on a shared understanding of the system, further research could be conducted to learn how large teams or organizations could effectively and openly collaborate in the recommended way.

Building on that idea, the authors believe that there is further potential to extend the possibilities of collaboration for innovation, through the Open Source movement, where users are treated as co-developers. This emerging movement, which has been applied mostly within software development, is spreading to different sectors like housing, agriculture, medicine, and machine design. Concepts such as Open Innovation and Open Design may be used in conjunction with the recommended approach to extend collaboration and understanding of the system even further.

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Appendix A: List of Interviewees and Collaborators

Name	Title, Organization, Location
Oya Akman	Industrial designer and consultant, Oya Design, Turkey
Mike Bertolucci	Executive consultant, Interface, USA (former President of Interface Research Corporation)
Sven Boren	Mechanical engineer, MSc student, BTH, Sweden. (former project manager at naval production company)
Gunnar Braaten	Senior consultant, Comperio AS, Norway
Olena Breyman	Marketing manager, Philips, The Netherlands
Per Brickstad	Senior product designer, PEOPLE PEOPLE, Sweden
Ronny Daniel	Architect and designer, MSc student, BTH, Sweden (formerly a designer at a design consultancy)
Liu Dongrong	Industrial designer, Linyi Normal University, China.
Aylin Doyle	Industrial designer, Ontario Science Center, Canada.
Amy Hunsicker	Cradle to Cradle, USA
Christopher Gavigan	CEO, Healthy Child Healthy World, USA
A. Idil Gaziulusoy	Ph.D. candidate and researcher in system innovation for sustainability, University of Auckland, New Zealand
Daniel Gunnarsson	Mechanical engineer, MSc student, BTH, Sweden
Gamze Guven	Industrial designer and consultant, Tasarimussu Turkey.

Si Juan	Industrial designer, Linyi Normal University, China
Song Kailiang	Strategic manager, Zhongxing Package Company, China
Chris Marquez	CEO, NCC, USA
Mike McGuire	Industrial designer, Wingspan, Canada
Hulusi Neci	Industrial designer, Neci Design, Turkey
Sun Ning	Freelance industrial designer, China
Jeff Patton	Consultant, teacher and Agile coach, AgileProductDesign.com, USA..
Dilek Ilker Piffaretti	Industrial designer, Noma Designers, Switzerland
Deniz Postaci	Sustainability consultant, writer, Turkey (former production and kaizen coordinator in the automotive industry)
Nicholas Russell	Sustainability consultant, Second Nature, UK
Kara Stonehouse	Industrial designer and MSc Student, BTH, Sweden (former designer at a multinational corporation)
Merve Titiz	Design consultant, sustainability entrepreneur, Turkey
Huang Xinyou	Strategic manager, Xinyou Products Company, China
Min Xingbao	Strategic manager, Lihua Package Company, China

Appendix B: Interview harvesting matrix

	For Businesses	For Design Teams
Drivers of existing products		
Why are new products designed?		
Barriers in current design practices		
Barriers for sustainability		
Barriers for innovation		
Strengths of current design practices		
Strengths for sustainability		
Strengths for innovation		
Weaknesses of current design practices		
Weaknesses for sustainability		
Weaknesses for innovation		
Opportunities of current design practices		
Opportunities for sustainability		
Opportunities for innovation		
Threats of current design practices		
Threats for sustainability		
Threats for innovation		

Appendix C: Experimental workshop

Title:

Newspaper Construction Workshop

Participants:

11 local adults with various professional backgrounds (not necessarily related to product development) participated in this challenge. They were divided randomly into three groups.

Purpose:

- To observe the process of people working with Agile, and the limitations or obstacles of working with Agile.
- To collect feedback on Agile processes
- To evaluate iteration 0 as a discovery phase.

Design challenge:

Design a pedestal to display a pot using only newspaper.

Context:

The pedestal is for a family of five - mother, father, two children, and a grandmother. They have a cat that roams the house freely. The pedestal will be used to display a sacred pot that has been in the family for hundreds of years. Once a year, the pot is taken out for a ceremony by the river.

They don't have a very large house, but will find a very special place to put this pedestal.

Process:

The facilitators addressed all participants as a group to describe the design challenge and background context. Participants were then split into three groups, and each group moved to a separate space. The workshop facilitators gave each group spoken and written instructions on the process they were expected to follow. Facilitators kept time for each group, and reminded them of process points if they strayed too far off track without intentionally modifying their process as a group. At the end of the working period, the groups came back together to present their results and reflect on the experience.

Group 1 – Plan-based stage-gate process.

- Agenda
    - 15 minutes – Plan project and write proposal
    - 5 minutes – Proposal sign-off
    - 40 minutes – Build
    - 10 minutes – Test and reflect

- Sample Plan Questions
    - Who will use what you build?
    - Where will it be?
    - What might it affect?
    - What will make it successful?
    - What do you expect to build?

- Sample Reflect Questions
    - What did you come up with? Was it what you expected?
    - What worked well?
    - What did not work well?
    - How did the process work?

Group 2 – Agile with no discovery stage.

- Agenda
    - 23 minutes – Plan, work, reflect and adapt
    - 23 minutes – Plan, work, reflect and adapt
    - 23 minutes – Plan, work, reflect and adapt

- Sample Plan Questions
    - What is the system of this product?
        - Who will use what you build?
        - Where will it be?
        - What might it affect?
    - What will make it successful?
    - What are your goals for this cycle?
    - What do you expect to be able to build and test by the end of this cycle?

- Sample Reflect Questions
    - What have you come up with? Is it what you expected?
    - What is working well?
    - Are some things not working well?
    - How is the process working?

- Sample Adapt Questions
    - What will you keep doing?
    - What will you stop doing?
    - What will you start doing?

Group 3 – Agile with Iteration 0/discovery stage.

- Agenda
    - 10 minutes – Talk about system and success of the project
    - 20 minutes – Plan, work, reflect and adapt
    - 20 minutes – Plan, work, reflect and adapt
    - 20 minutes – Plan, work, reflect and adapt

- Sample Plan Questions
    - What is the system of this product?
        - Who will use what you build?
        - Where will it be?
        - What might it affect?
    - What will make it successful?
    - What are your goals for this cycle?
    - What do you expect to be able to build and test by the end of this cycle?

- Sample Reflect Questions
    - What have you come up with? Is it what you expected?
    - What is working well?
    - Are some things not working well?
    - How is the process working?

- Sample Adapt Questions
    - What will you keep doing?
    - What will you stop doing?
    - What will you start doing?

Results of the experiment:

Group 1 – Plan-based stage-gate. The linear process group was very comfortable with their process. They did not touch or test out the material while conducting their 15 minute planning session. At the end of the planning session, they presented a proposal to the authors that included success criteria as well as a sketch of the display they planned to make. The authors signed off on the proposal before the group began to build their display. This group made many changes to their original design over the course of construction, but did not see the need to ask permission for changes from the original plan. They felt that they were acting in a very flexible way and considered this a positive quality. However, when reflecting internally on their result at the end of the process, and during their presentation to the group, they very clearly justified the end result by framing it as a successful answer to their written out, high-level success criteria. They did not point out the difference between the result and the initial drawings included in their proposal. When questioned about this difference, they attributed it to the fact that the initial idea had been too complicated and the material did not work as they expected.

Group 2 – Agile with no discovery stage. The Agile group with no planning stage spent most of their first iteration planning, and struggled to begin working with the material. Once they began, they engaged in rapid prototyping activities designed to test the qualities and strength of the material. One team member suggested sketching and agreeing on a design idea, but others decided that it would be more efficient to start by trying to build structural components and to see where that might take them. This group had a very difficult time performing each step of the iterative cycle within the given time box, but generally responded well to the idea of working in cycles and continuously trying out new ideas, even making last minute changes at the very end of the third cycle, collaboratively and without hesitation.

Group 3 – Agile with Iteration 0. The Agile group with a discovery stage at the beginning had some initial difficulty deciding on high-level goals before jumping into detailed planning. They very quickly formed a shared vision that included a construction concept, and moved forward with that construction plan through all three successive iterations. One team member reflected that this plan was selected because nobody had offered up an alternative, and others reflected that they saw no reason to change it, so kept going. The complexity of the design and the time constraints would have made it difficult to try out additional ideas in the course of the project, but regular reflections failed to bring in new ideas. Instead, they built consensus around moving forward with the original idea.

Conclusions:

Agile is a new approach for most people and requires coaching. While Agile approaches can promote flexibility in design and in process, they are in fact very structured. Changes can be made in the process, but should be made in a considered way and agreed upon by all members of a design team. People may feel not comfortable when they first use Agile. They need more time to practice and get used to it.

Shortcomings of the experiment:

Both Agile groups felt pressured by the short time-box limits of the experiment and chose to continue working while reflection questions were asked. In a redesigned workshop, the conductors might reiterate the idea that plans should be manageable within a time box and that participants should step away from work to reflect. Continuing to work on a current idea while reflecting may have made it difficult to switch directions.

Appendix D: Expert review questions and evaluation matrix

Reviewers were provided with a summary of the recommended innovation approach, along with descriptions of each relevant tool or concept. They were asked to answer the following questions:

1) Does this approach clarify a path to take products towards sustainability?

2) Does this approach outline a manageable process that you could implement in your day-to-day work?

3) Are there any similarities between this approach and your current design practices?

4) If you do not see a practical use for this approach in your day-to-day work, are there different circumstances that would make it more practical or do you think it might be more appropriate for another industry sector? Please explain.

5) Where would you have trouble following this approach? Why?

6) Are there any aspects that seem unnecessary? Why?

7) Are there any aspects of this approach that seem particularly helpful? Why?

8) Are there any tools or concepts that you would recommend adding to this approach?

9) Do you see potential for supplementing products with services to create product-service systems using this approach?

10) Any other comments or recommendations?

Reviewers were also asked to rate tools and concepts on a scale of 1-5, where 1 was low (not very clear, not very practical, etc.) and 5 was high (very clear, very practical).

Tool or Concept	**Clear?**	**Practical?**	**Useful for Innovation?**	**Useful for Sustainability?**
The 4 Sustainability Principles				
Backcasting				
MSPD				
TSPDs				
SLCA				
Life-cycle Maps				
Causal Loop Diagrams				
Leverage Points				
User Research / Needfinding				
Regular User Testing				
Need Maps / Personas				
Iteration 0/High-Level Pre-Planning Stage				
High-Level/Non-Detailed Vision of Success				
Iterative Cycles				
Cross-Functional Teams				
Including all Stakeholders in Meetings				
Iteration Planning Meeting				
Daily Check-In Meetings				
Iteration Retrospective Meetings				
Rapid Prototyping				
Continuous Improvement				
Lean				

Appendix E: Sample sustainability questions from the Method for Sustainable Product Development (MSPD)

Product Function

1. Is the product dissipative?
   A dissipative product means that the material contained in the product is spread to nature during use, e.g. pesticides, detergents, paints, brake pads. In order for a dissipative product to be used in a sustainable society, there are high demands on material content (see materials module). To reduce the material restrictions, it is best if the product is not dissipative.
2. What are the possible product concepts that are not leading to a dissipative use of the product and still satisfying the selected need?
3. Does the product concept transfer energy or materials during the product's use phase?
   Various studies have shown that a large part of the environmental impact of a product occurs during the use phase due to additional energy and materials. To avoid this impact choose, if possible, a product that does not require energy or materials incorporated during the use phase.
4. What are the possible types of products available that do not require energy or materials during the product's use and that meet the selection need?
5. What needs does the product meet?
   In products with multiple functions that meet multiple needs, it is possible to reduce the number of products and thus reduce the amount of materials to meet those needs.
6. What are the possible types of products available that can meet multiple needs in addition to selected need?
7. Is the product suitable for multiple users?
   In products with multiple users, it is possible to reduce the number of products and thus reduce the amount of materials to meet the needs of users.
8. What are the possible types of products suitable for multiple users?
9. Does the product include a system for reuse/recycling? Some of the materials that are products are included in the system for reuse/recycling.

10. What are the possible types of products available that can encourage reuse and recycling, such as service rather than physical product (leasing)?

Product Construction

1. Use energy, materials, or biologically productive areas in the use phase in a manner that does not fit into a sustainable society?
2. How can the product be constructed (instead) so that the energy, materials, or biologically productive areas are used in a way that fits in a sustainable society?
3. Is the product powered by fossil fuel?
4. How can the product be designed so that energy from renewable energy sources (either directly or through electricity) can be used (instead) to run the product?
5. Are there dissipative-use materials that cannot be incorporated into natural cycles in the use phase, i.e. metals unusual in nature or chemicals that are persistent in nature? (Ex. brake fluid, coolant to a car)
6. How can the product be designed so that materials can be used that can be incorporated into natural cycles, i.e., common metals, readily biodegradable chemicals or renewable materials?
7. The user can be made to switch to materials that can be incorporated into natural cycles, through information, i.e., common metals, readily biodegradable chemicals or renewable materials?
8. Will the use of the product lead to a systematic loss of biodiversity and long-term productive capacity due to manipulation of natural systems?
9. How can the product be designed to avoid the systematic impoverishment of biodiversity and long-term productive capacity, due to manipulation of natural systems?
10. Is the use of materials, energy or bio-productive surfaces during the use phase inefficient?
11. Is efficiency optimized when using the product?
12. How can the product be designed so that the efficiency of use is optimized?
13. Is it possible to maximize efficiency by getting better information to the user?
14. Are there direct emissions from the use of the product?
15. How can the product be designed to reduce emissions during use?

For example, proper care of the product may result in reduced emissions.

16. Is the lifetime of the device optimized?
    Material flow (and associated energy flows) can generally be reduced with a longer lifespan of products.
17. How can the product be designed to achieve an optimal lifespan?
18. How can the product be designed to achieve a timeless and classic design so that the product does not need to be discarded because of outdated fashion?
19. How can the product be designed so that all product parts can easily be replaced or repaired easily?
20. How can the quality of each component be improved so that they last longer? (e.g. physical protection)
21. How can the product be designed so that it is easy to maintain?
22. Does the design allow a high reuse or recycling rate?
    Closed-loop systems in society can be achieved with a high level of reuse / recycling rate.
23. How can the product be designed so that the whole product can be part of a recycling system?
24. How can the product or product components be designed so that the reuse of product parts can be increased?
25. How can the product parts be designed so they are easy to separate?
    Consider sandwich construction, easily accessible areas, visible parts, bonding.
26. How can the product be designed so that material from the product can be recycled?
27. Can you change the material in certain product components so that the recovery of materials from several product parts can be together?
    If there is only one material in the product, it is compatible.
28. How can the product / product components be designed so that different materials easily separable from each other for increased recycling?
    Can the quality of the material be maintained during recovery by not mixing materials?
29. Go there to find materials to facilitate recycling?
30. Is the product designed for an energy-efficient transport of the product?
31. How can the product be designed to reduce energy consumption in the transport of the product?

32. How can the product/components be reduced in weight to reduce energy consumption in the transport of the product?
33. How can the product/components be designed to be packaged efficiently, thus reducing transport of the products?

Materials

1. What materials are used that cannot be incorporated into the natural cycles, namely rare metals in the environment or chemicals that are persistent and foreign to nature?
2. (Instead) What materials can be used that are part of natural cycles, i.e. metals commonly found in nature, readily biodegradable chemicals or renewable materials?
3. What materials have a quality (e.g., alloy) that is not necessary to the function or the product / product component's life?
4. How can the quality of the material (e.g., alloy) be adapted to match the required function or product component / product length of life?
   If the material wears out before the product, then consider whether you can make the material more durable, e.g., another alloy or paint. If the material is more durable than the life of the product or function calls, maybe you can use a less advanced alloy.
5. What materials are used in unnecessarily large amount for the product / product component's functions?
   In a sustainable society materials are used efficiently, e.g., not more material than the function requires.
6. What materials in the product section can be used in smaller quantities?
7. How much can the amount of material be reduced (a little, some, a lot)?
8. What materials have resulted in large emissions of substances that cannot be incorporated into natural systems upstream, i.e. the extraction or transport processes in the suppliers?
9. What materials can be used (instead) that do not involve major issues of emissions that cannot be incorporated into natural systems upstream, i.e. the extraction, and transport processes in the suppliers?
10. What materials has led to the systematic degradation of biodiversity and long-term productive capacity due to manipulation of ecosystems upstream, i.e. the extraction, cultivation and harvesting by subcontractors?

11. What materials can be used (instead) that do not involve the systematic loss of biodiversity and reduced long-term productive capacity due to manipulation of ecosystems upstream, i.e. the extraction, cultivation and harvesting by subcontractors?

Production

1. In what way does the production system affect the environment negatively?
2. How can today's production system change so that it fits into a sustainable society?
   In a sustainable society the production system is probably efficient and economical. Spillage and disposal are most likely limited and most materials are reused extensively. Chemical products are carefully selected to minimize environmental impact and promote a good working environment.
3. What fossil-based energy is used for the production system based?
4. What renewable energy sources can be used for the production system?
5. What is being done today with regard to materials and energy consumption that will be reduced with production?
6. How can material consumption and energy consumption in production be reduced through more efficient production processes?
7. How can the waste and emissions be minimized through more efficient production processes and the reuse/recycling system?
8. What un-natural contaminants and/or persistent substances are used in production?
9. Which foreign and persistent substances can be changed to less environmentally damaging substances?
10. How can the production processes and/or extraction processes be changed so that nature is not damaged or depleted?
11. How are those working in the production environment affected negatively by the way the existing production system works?
12. What can be changed with regard to the social environment that would be better in terms of air, noise, light, physical and mental work?
13. What transport used by the company for the production system?
14. How can the transport during production be minimized or made more efficient?
15. Are fossil fuels used for transport vehicles?

16. What are alternatives to fossil fuel vehicles? E.g. what renewable fuels can be used, or where can (renewably-generated) electric power be used?

Supply

1. What materials, resources, etc. are purchased that result in the release of substances, manipulation of biologically productive space or allocating resources (equity issues) that do not fit into a sustainable society in the earlier part of the product life cycle, i.e. the mining, farming/harvesting, processes or transport?
2. From which suppliers you can purchase materials, resources, etc. that:
    - primarily (backcasting): do not emit substances, manipulate biologically productive space or unfairly allocate resources in ways that do not fit into a sustainable society in the earlier part of the product life cycle?
    - secondly (forecasting): leads to less emission of pollutants, lower impact of biologically productive areas, or not so great extent to an unfair distribution of resources at the upstream in the product life cycle?
3. What materials, resources, etc. are purchased, leading to release of substances or manipulation of biologically productive areas that do not fit into a sustainable society in the mining (removal of raw materials from the earth's crust)?
4. From which suppliers you can purchase materials, resources, etc. that during mining:
    - primarily (backcasting): do not emit any substance or manipulate biologically productive areas that do not fit into a sustainable society?
    - secondly (forecasting): leads to less emission of substances or lesser influence of biologically productive areas?
5. What materials, resources, etc. are purchased that lead to the emission of substances that do not fit into a sustainable society in the production processes of suppliers?
6. From which suppliers can you purchase materials, resources, etc. that:
    - primarily (backcasting): do not emit substances that do not fit into a sustainable society in their production processes?

    - secondly (forecasting): leads to less emission of substances in production processes?
7. Which energy suppliers can provide electricity from renewable energy sources?
8. What materials, resources, etc. are purchased, leading to release of substances or manipulation of biologically productive areas that do not fit into a sustainable society in the cultivation and harvesting?
9. From which suppliers you can purchase materials, resources, etc. that:
    - in the first place (back-casting) do not lead to the emission of substances or manipulation of biologically productive areas that do not fit into a sustainable society in the cultivation and harvest?
    - secondly (forecasting): leads to less emission of substances or lesser influence of biologically productive areas of cultivation and harvesting?
10. Which energy suppliers can provide electricity from biofuels whose cultivation/harvesting does not lead to systematic impoverishment of biodiversity and long-term productive capacity?
11. What materials, resources, etc. are purchased, leading to unfair distribution of resources or otherwise unethical circumstances (e.g. child labor) at the earlier stage of the life cycle (usually relevant to the ownership and trade?)?
12. From which suppliers can you purchase materials, resources, etc. that:
    - in the first place (back-casting) does not lead to an unfair distribution of resources or unethical conditions at the upstream of the product life cycle (fair trade / fair trade)?
    - secondly (forecasting): not in as great degree leads to an unequal distribution of resources or unethical conditions at the upstream of the product life cycle?
13. What materials are purchased that are not part of a reuse/recycling system?
14. From which suppliers you can purchase materials, resources, etc. that:
    - in the first place (back-casting) can be classified as reused/recycled materials and which would otherwise not require raw material acquisition?

- on the other hand, (forecasting) has a high proportion of reused/recycled materials and which would otherwise require some raw material acquisition?

15. Do you use subcontractors that require long-distance transport to supply you with materials/products?
16. From which suppliers you can purchase materials, products, etc. that are closer to you so that transport can be reduced?
17. Do you use subcontractors that do not have a policy for how their own environmental impact and resource consumption can be reduced?
18. Which supplier can you switch to that has or has a plan to become less environmentally damaging and resource-efficient?

Appendix F: Thesis blog

The authors created a blog to provide a medium for discussions, keep track of developing ideas and expose them to stakeholders for feedback. The blog was only partly successful. It failed to become a forum for direct discussions between stakeholders, but did facilitate conversations between the authors and individual experts. It was also helpful in keeping track of research developments.

The blog can be viewed at http://agilethesis.wordpress.com